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Human Biology - Lives of Cells

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Author
The Program in Human Biology, Stanford University

Contents

Chapter 1

Introduction to Lives of Cells - Student Edition (Human Biology)

1.1 Human Biology: An Interdisciplinary Life Science Curriculum

An inquiry-based guide for the middle school student.

Originally developed by the Program in Human Biology at Stanford University and

EVERYDAY LEARNING®

1.2 Introduction to Lives of Cells

Contents

Authors

H. Craig Heller, Principal Investigator

Mary L. Kiely, Project Director

Text Author

Ellen Porzig

Activity Authors

Stan Ogren, Ellen Porzig, Geraldine Horsma, Marjorie Gray

Project Editor

Dennis McKee

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Margy Kuntz for her review and edits of the field-test version of *Lives of Cells.*

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Everyday Learning Development Staff

Editorial

Steve Mico, Leslie Morrison, Susan Zeitner

Production/Design

Fran Brown, Annette Davis, Jess Schaal, Norma Underwood

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Chapter 2

Building Blocks of Life - Student Edition (Human Biology)

2.1 Building Blocks of Life

Mayan pyramid, Chichen Itzah, Mexico showing its distinct building blocks.

What are cells?

You started life as a single cell. Each person does. First, you were just one cell. You became the person you are today as a result of cell division. Cell division produces the many special cells that form a human being.

Mini-Activity

Using a Microscope to See Cells Use a microscope to observe prepared laboratory slides of

1. Red blood cells
2. White blood cells
3. Skin cells

4. Lung cells
5. Heart muscle cells
6. Skeletal muscle cells
7. Bone cells

First observe the slide of tissue showing cells on the slide without the use of the microscope. Then put the slide under the microscope at low power. Switch to higher power so you can actually see the details of the cells. Make a drawing of what you see through the microscope. Include appearance, shape, and anything else that you think is important.

Cells are the basic units of life. We are made of cells. Cells can make copies of themselves. Some cells can produce other kinds of cells that are different from themselves. Cells are small, and they come in a variety of shapes and types. Cells have different functions. Cells can move, swim, and crawl.

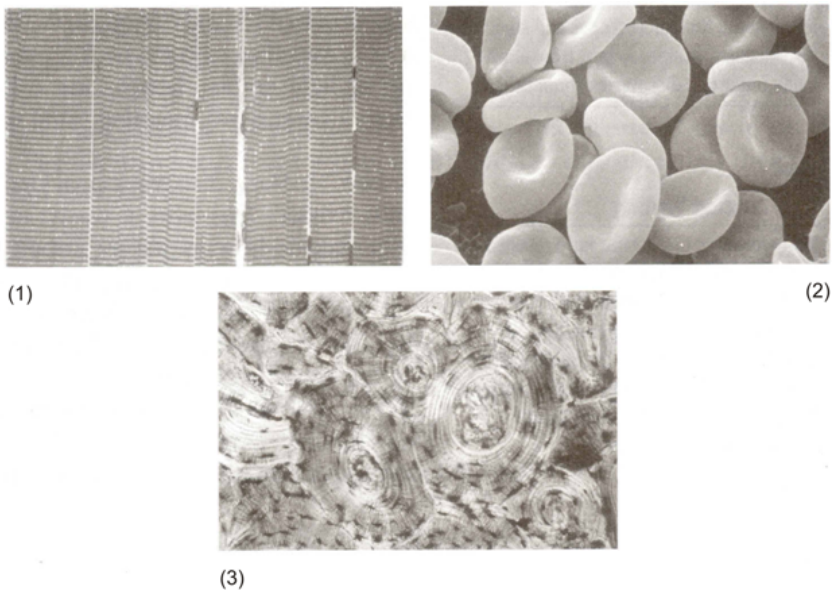


Figure 1.1 Examples of typical mammalian cells showing their diversity in shape. (1) Striated muscle cells, (2) red blood cells, and (3) bone cells (osteocytes).

Did You Know?

Some cells produced by cell division are programed to die. That explains how blood vessels become hollow tubes. Blood vessels develop as solid tubes. The cells in the center die and are removed, allowing for space for the blood. In the early stages of development of the hand it was paddle-shaped. The cells located in what is now the space between the fingers were programed to die.

Cells can send signals to other cells. Sometimes cells need to touch each other to send a signal, and some cells have long processes or extensions so they can send signals over long distances. Other cells release chemical signals that are carried all over the body by the blood. Once a cell receives a signal, it can interpret the signal and decide what to do. The cell can decide to divide. It can decide to become a specialized cell type. For example, it can become a red blood cell that gets rid of its nucleus. It can become a nerve cell in your eye. It can become a muscle cell of your heart. A cell can even decide to die.

Cells make the important materials that build a person. Cells make bone and cells make blood. In fact, every organ in your body, including your brain and your heart, is made of special cells. Cells make the substances necessary for life.

Each part of a cell is dynamic. The pictures you have seen of cells may make them look frozen. That's because a scientist or lab technician prepared the specimen to get it ready to be viewed in a microscope. But in life, cells are very active. Cells move and have dynamic, active behaviors.

Cells have many parts. Each part of cells has a special job. For example, cells have a boundary called a membrane. The membrane keeps some materials out, and other materials in, just like the border of a country. The membrane has channels and gates that let some materials come in and some go out. Most of the activities of a cell are controlled by its most important part, the cell nucleus. The genetic material of a human cell is contained inside the nucleus. You will learn more about these parts and other parts of the cell later in this unit.

Journal Writing

The existence of cells was first supported only after the discovery of the microscope. Do a library search to find out who invented the first microscopes and some of the scientists, besides Robert Hooke, who made important discoveries about cells.

Scientists first learned about cells more than 300 years ago. During the 1660s, an English scientist named Robert Hooke built a simple microscope out of magnifying glasses. When he used his invention to look at a very thin slice of cork, he discovered that the cork seemed to be made up of little empty "boxes." He called these boxes cells, which comes from a Latin word meaning "little rooms."

Journal Writing

Many scientific discoveries have resulted from one person exploring something simply because of curiosity. Have you ever watched an ant trail for a long time or observed the patterns on the surface of the moon? Describe in detail your observations of something you've "studied" simply because you were curious.

Robert Hooke's discovery provided scientists with the knowledge that cells existed. However, it wasn't until the late 1830s that several scientists realized how important Robert Hooke's findings were. At that time, scientists observed that all plants and animals were made of cells. About 20 years later, scientists discovered that all cells come from other cells. In other words, cells reproduce. These two ideas form the basis of one of the most important theories in biology-the **cell theory.** The cell theory describes what cells are and how they function. It states that cells are the units of structure and function of organisms. In addition, the theory states that all cells come from pre-existing cells.

The Organization of Living Things

Some organisms, such as an amoeba, are made of only one cell. Singlecell organisms are called unicellular organisms. Most organisms, however, are made of many cells. Organisms that contain many cells are called multicellular organisms. Humans are an example of a multicellular organism-your body contains trillions of cells!

What Do You Think?

Consider the very different functions of blood cells, nerve cells, and muscle cells. (a) Do you think all these cells look alike? Why or why not? (b) Do you think one kind of cell could perform the functions of another? Why or why not?

Multicellular organisms are made up of many cells, and of many types of cells. The different types of cells work together to perform the many different functions that keep you alive. For example, one type of cell is

a blood cell. Red blood cells carry oxygen to different parts of your body and carry carbon dioxide away from different parts of your body. Other blood cells attack viruses and bacteria that invade your body. There are also fragments of blood cells that are in your blood to help repair wounds. Another type of cell is a nerve cell. Nerve cells control your body's reactions to events that happen inside and outside your body. Nerve cells send signals to your muscle cells to make them contract. Other nerve cells enable you to see and hear.

Sometimes groups of similar cells work together to perform a specific function. A group of similar cells working together to carry out a specific function is called a **tissue.** For example, the skeletal muscle in your arm is a tissue made up of many muscle cells. Each individual muscle cell can contract and relax to make your arm move. But a single cell alone cannot move your arm because your arm is too heavy. So all the muscle cells work together. Some are contracting and others are relaxing at the same time. By working together as a tissue, the cells make your arm move in a certain way.

Mini-Activity

Relative Size of a Cell How big is a cell of your body as compared to a molecule in your body such as DNA? How big is a cell of your body as compared to an organ such as your lung? To learn about relative sizes of selected parts of your body, place the following structures in decreasing order of size. (Begin with the largest structure.) Even though you have not learned about each of the following, do your best to put them in the correct order.

A. Arm

B. Blood cell

C. Cell nucleus

D. Chromosome

E. DNA

F. Human body

G. Lung

H. Nose

I. Skeleton

All cells can be grouped into four general tissue types. (1) **Muscle tissue** is made up of cells that can contract. (2) **Epithelial tissue** is made up of cells in sheets. These sheets of cells line your breathing and digestive systems, cover the organs of your body, and form your skin. (3) **Connective tissue** is made up of cells that support and hold things together such as cartilage, tendons, and bones. Blood cells are also connective tissue. (4) **Nervous tissue** is made up of cells that can process information and send electrical signals throughout your body.

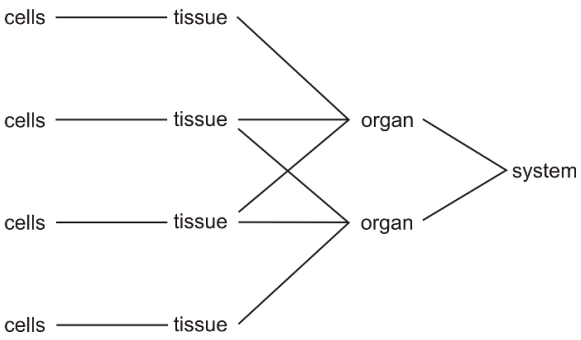


Figure 1.2 Cells make up tissues. Tissues make up organs. Organs make up systems.

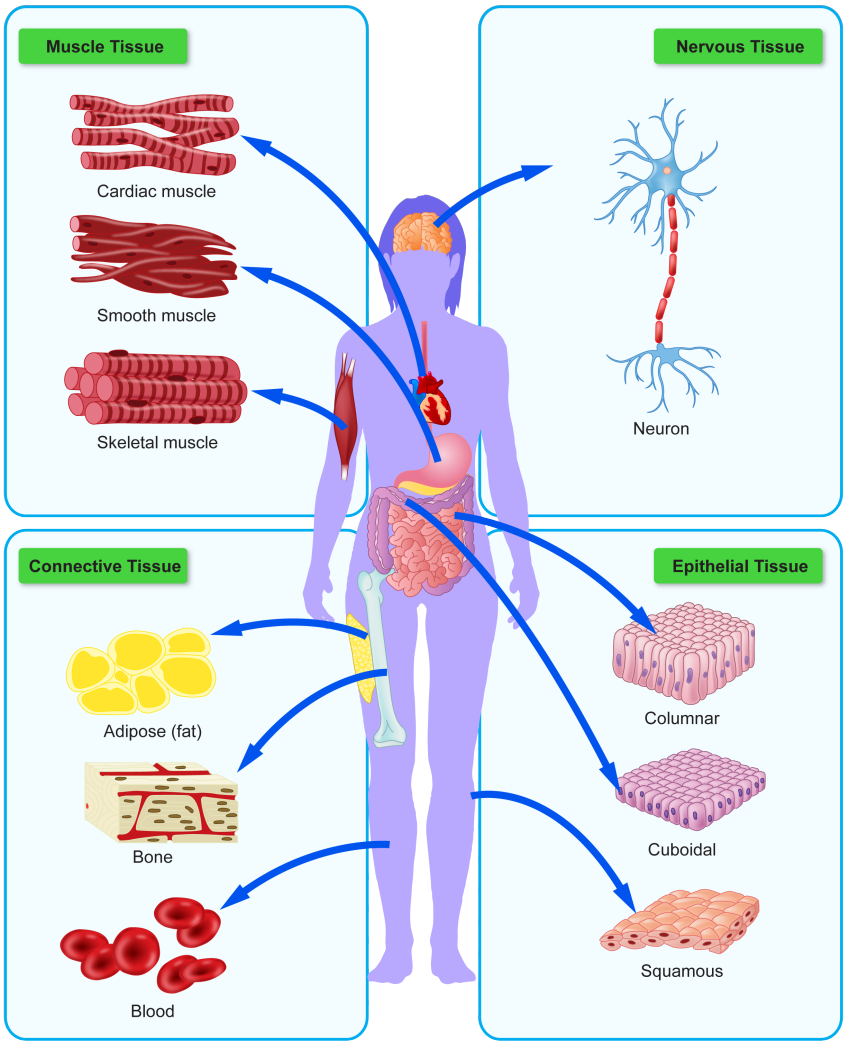


Figure 1.3 All cells in the human body can be grouped into four general tissue types.

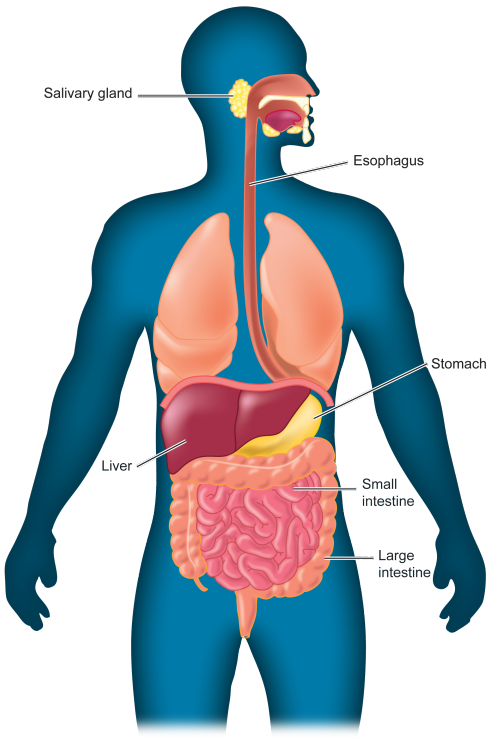


Figure 1.4 The human digestive system.

Several different kinds of tissues also can work together to perform specialized functions. A group of tissues that work together is called an **organ.** Your heart is an organ that contains muscle, nerve, and connective tissues. These tissues work together to pump blood throughout your body. Your stomach is an organ that helps you digest the food that you eat.

Journal Writing

Write down your three favorite activities or interests. Here's an example:

1. Playing sports
2. Talking on the phone with friends
3. Listening to music.

Write a list of some of the cells that you think are involved in those activities. Make guesses and don't worry about the terminology. Later you will know more about the names and functions of cells.

Organs that work together form a **system.** Your body has ten different organ systems, each of which does a different job. You can digest food, for example, because of your digestive system. The digestive system is made of several different organs, including your stomach, small intestine, large intestine, and liver. Your heart and all of your blood vessels form your cardiovascular (cardio = heart and vascular = vessels) system, which pumps and circulates blood throughout your body.

Together, all the different cells, tissues, organs, and systems work together to provide a suitable "internal environment" for all of your cells. Each cell has needs, and together all of the organ systems maintain an environment inside your body that takes care of the needs of each and every cell. Knowing what cells are and how they work helps us learn more about the human body and how it functions.

Mini-Activity

Imagine a One-celled Human Imagine the impossible. Could a human being be made up of just one giant cell?

What would the problems be?

What would hold this one huge cell together?

What would the cell look like?

How could the cell have any shape?

Will the cell be able to live on land, or will it have to live in water?

How could the cell have arms and legs?

How could the cell move?

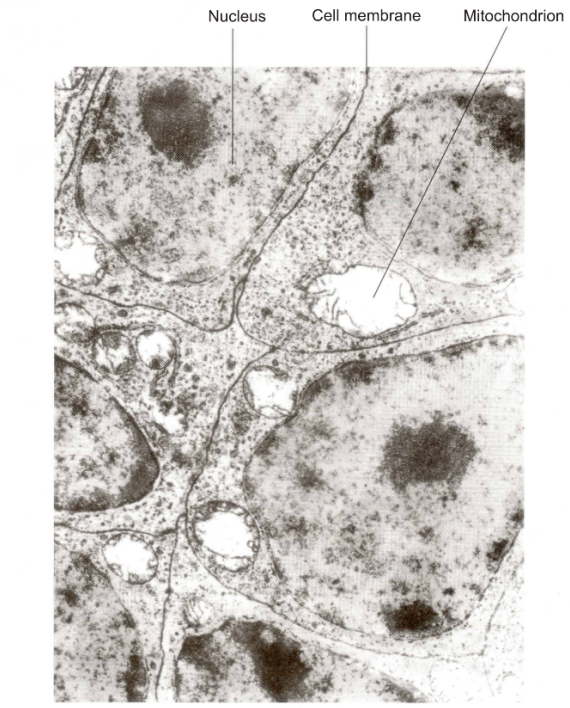
How could the cell make more cells?

What problems would this one-celled human face? Be creative. Use your imagination as well as your knowledge of human biology.

The Size of Cells

Why is a person not just one huge cell? Why are we made up of so many tiny cells? Why are cells so small? Why does it take so many billions of cells to build a person? Let's consider an alternative design. Instead of a person being made from millions of tiny cells, could a person be made up of one giant cell?

One real problem for a one-celled human would be maintaining an adequate supply of oxygen and nutrients and maintaining an adequate rate of elimination of wastes, such as carbon dioxide. The exchanges of nutrients, oxygen, and wastes, such as carbon dioxide, would have to be across the cell's outer membrane. The bigger the cell, me more it must exchange with the environment around it. Those exchanges would all have to go across its one big cell membrane. This creates a situation called the surface/volume problem. The surface/volume problem can best be explained in terms of mathematics, as you will see in Activity 1-1.



These skin cells are magnified 2,500 times.

Activity 1-1: Why Are Cells Small?

Introduction

What happens when a cell increases in size? How does an increase in size affect the efficiency of the functions of the cell, especially the functions of the cell membrane? You should be able to answer these questions after completing this activity.

The purpose of this activity is to help you learn about what happens to a cell when it increases in size. You explore cells having the shape of cubes (cuboidal, like dice). Cuboidal cells are found in your kidney, thyroid gland, and salivary glands.

When you finish, you should be able to propose answers to questions such as, Why are cells small (microscopic) in size? Why do cells divide?

Materials

- Plain paper for constructing a model of a cube
- Scissors
- Metric ruler
- Clear tape
- Activity Report

Procedure

Step 1 Use the materials provided to explore the question below:

What are the surface area and volume for a cube-shaped cell?

If you dismantle a cube 1 *cm* on each side and lay it flat, it would look like the drawing in Figure 1.5 below. Use this information to complete Part A on your Activity Report.

Step 2 Build a model to show what happens to a cube-shaped cell when it doubles in size. If you dismantle a cube 2 *cm* on each side and lay it flat, it would look like the drawing in Figure 1.6. Use this illustration to help you complete Part B on your Activity Report.

Step 3 Dismantle your 2 – *cm* cube. What happens to the relationship between surface area and volume when a cube-shaped cell doubles in size? Complete Part C on your Activity Report.

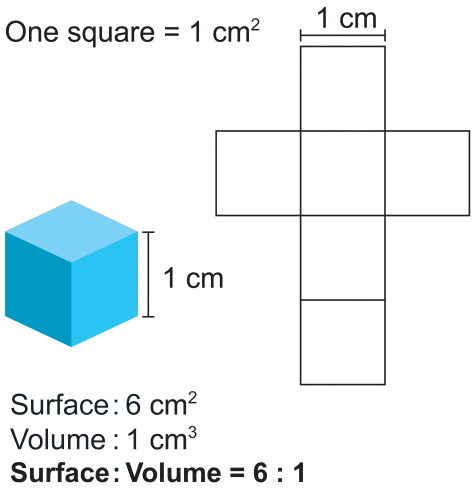


Figure 1.5

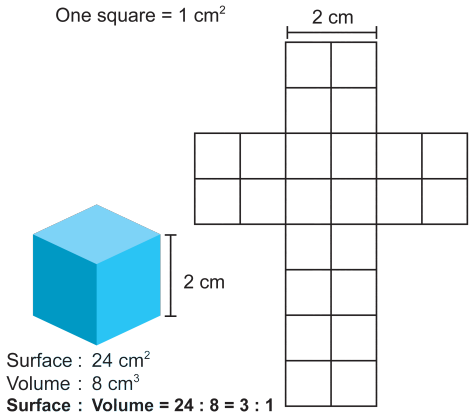


Figure 1.6

Apply Your KNOWLEDGE

When animals use the energy they get from food, they lose a lot of that energy as heat radiating from the surface of their bodies. Explain why small animals, such as a mouse or a hummingbird, have to spend most of their time eating.

Because of the surface area/volume problem, single-cell organisms must be very small. Multicellular organisms can be bigger because they are made up of large numbers (sometimes billions and trillions) of many different kinds of cells. Many millions of cells can make up breathing systems and digestive systems. These systems depend on different types of specialized cells that work together.

Besides being small, the cells in the human body vary in shape. Some are cuboidal, such as some epithelial cells that line body cavities. Other cells are more rounded (spherical), such as red blood cells. Some cells

are shaped like a rectangle (columnar), such as those found in the lining of the digestive tract. Some highly specialized cells, such as nerve cells and white blood cells, have irregular shapes. The shape of a cell is related to its function in your body. Think about this relationship as you learn about different types of cells and what they do.

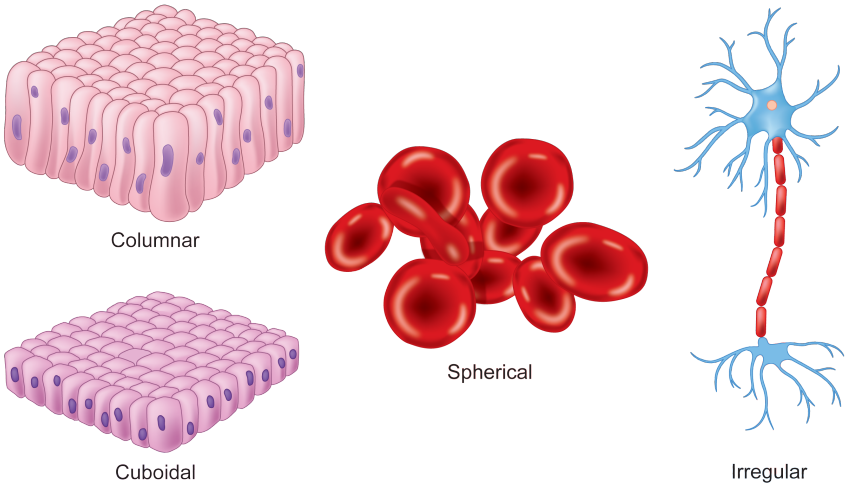


Figure 1.7 Examples of cells with different shapes that make up different tissues in your body.

Mini-Activity

How Changes in Surface Area and Volume Affect Cells with Different Shapes Is the pattern of surface area and volume changes with increasing size the same for all cells regardless of shape? Use a spherical-shaped cell as a model and the formulas for surface area and volume of a sphere to explain your answer.

Surface area of a sphere $= 4\pi r^2$

Volume of a sphere $= \frac{4}{3}\pi r^3$

To simplify the surface/volume ratios, use $\pi = 3$.

Look at Figure 1.8.

1. What happens to the surface area to volume ratio as cells increase in size?
2. What effects does this change have on cell functions?

Table 2.1:

Radius (cm)	**Surface Area** $(A = 4\pi r^2)$	**Volume** $\left(V = \frac{4}{3}\pi r^3\right)$	**Surface Volume**
1 *cm*	12 cm^2	4 cm^3	$\frac{12}{4}$ or 3 : 1
2 *cm*	?	?	?
3 *cm*	?	?	?
4 *cm*	?	?	?

Figure 1.8 Surface Area and Volume for Spheres.

Why Are Cells Important?

Your overall health depends partly on keeping your cells healthy. Diseases, such as cancer and heart disease, stem from changes in the functions of cells. Cells live and do their work in a dynamic relationship with the entire body. There is a delicate balance of interactions between cells that allow tissues, organs, and systems to function well. The life of a cell depends on events that take place within it and on the environment surrounding it.

Cells and tissues live in a fluid environment. The body's fluids bathe all of the cells of the body. Cells get oxygen and nutrients from these body fluids. Cells discharge wastes, such as carbon dioxide, into these fluids. So the activities of cells tend to change their environment. But their health requires the environment to have enough oxygen and nutrients and not too much waste. How does this problem get solved? Different types of cells, different tissues, and different organs all contribute in different ways to keep the cell's fluid environment constant. Maintaining balance of your internal environment under changing conditions is called **homeostasis.**

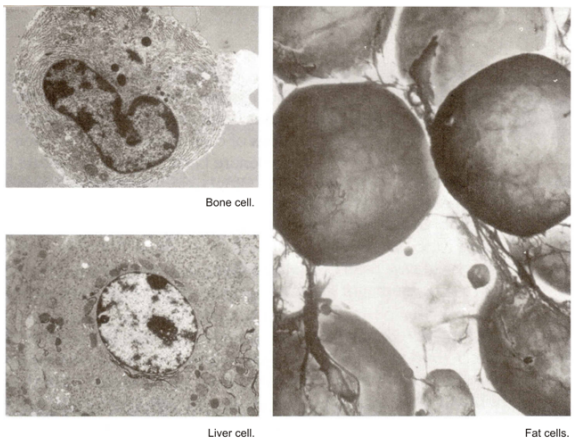
Review Questions

1. Describe four characteristics or functions of cells.
2. Describe the cell theory in your own words.
3. What is the relationship between a cell, tissue, organ, and system? Include examples.
4. Why are cells so small?
5. Why is homeostasis important to cells?

Chapter 3

Cell Parts and Their Functions - Student Edition (Human Biology)

3.1 Cell Parts and Their Functions



What is the structure of cells?

Each cell is surrounded by a membrane and contains parts called cellular organelles. Each cellular organelle has a specific function. Some parts of a cell are involved in converting energy from nutrients in the food you eat into a form of energy that the cell can use. Other parts of the cell are involved in storing the genetic information that serves as the blueprint that makes you different from a gorilla or a hummingbird. Still other parts of a cell are responsible for building the proteins that enable the cell to do its many tasks.

The Cell Membrane

Every cell has a thin outer covering called the **cell membrane,** or plasma membrane. The cell membrane surrounds the contents of the cell and separates it from other cells and the environment. The cell membrane also controls what materials go into and out of the cell. For example, the cell membrane allows nutrients and oxygen to move into the cell, and carbon dioxide and waste materials to move out of the cell.

The cell membrane is made of molecules called proteins and lipids arranged in an orderly manner. You

could think of the cell membrane as two sheets or layers of lipid molecules with different kinds of proteins positioned in the sheets. The lipids making up the bilayer membrane are arranged in a special way. Each lipid molecule has a head and a tail.

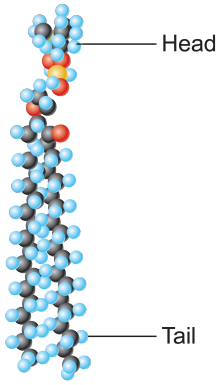


Figure 2.1 A typical lipid molecule found in the cell membrane.

The head ends of the lipid molecules are attracted by water, and the tail ends are repelled by water. In a watery environment, the lipid tail ends tend to associate with (face) each other. Since the head ends are attracted by water, they face the watery environment, some toward the inside of the membrane and some to the other side of the membrane. In a cell membrane, each lipid layer has its molecules lined up in the same way. The two layers are arranged so the tails of the lipid molecules face each other.

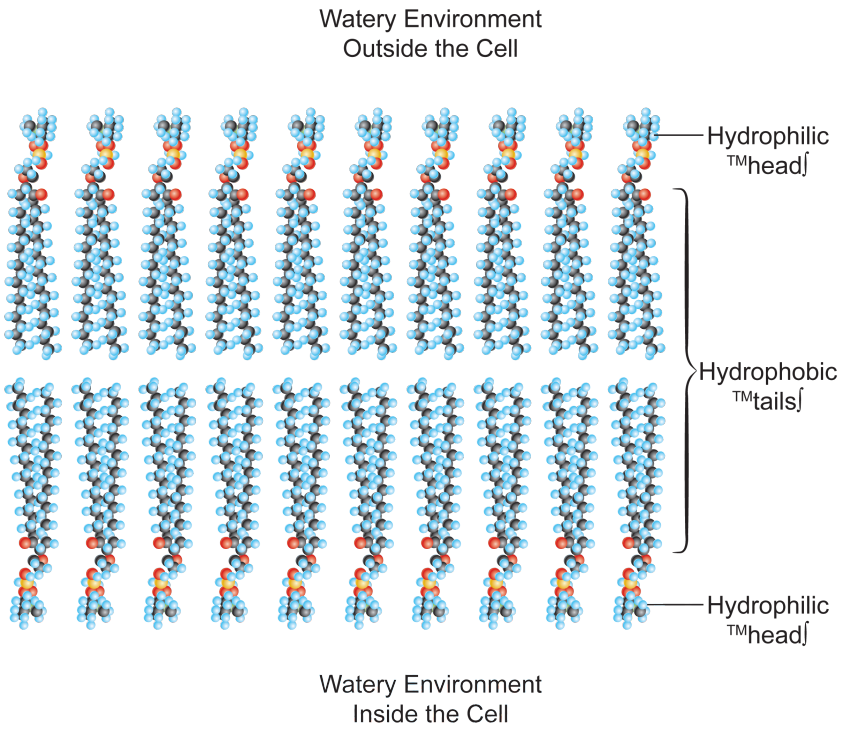


Figure 2.2 Bilayer sheet of lipid molecules, as in a cell membrane.

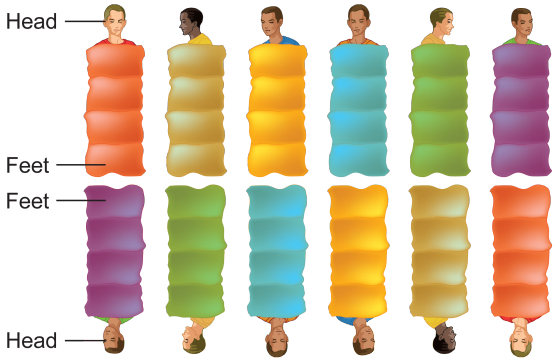


Figure 2.3 Scouts in two rows of sleeping bags.

Mini-Activity

A Drawing or Model of a Cell Membrane Draw your own picture or build a model to show the arrangement of lipids in a cell membrane.

Think of a troop of scouts all sleeping in their sleeping bags in a rectangular tent. They want to arrange themselves so no one's feet are in someone else's face. One arrangement would be two rows of sleeping scouts with feet pointing toward each other as shown in Figure 2.3. That arrangement is similar to the composition of the lipid bilayer of the cell membrane.

Did You Know?

A person coming out of the bath carries away a film of water about $\frac{1}{50}$ of an inch thick. This water weighs about a pound. A mouse getting out of the same tub carries away water about equal to its own weight. A fly or honey bee coming out of a pool of water carries a film of water that weighs many times more than its own weight.

The organized lipid bilayer allows water and molecules that dissolve in water to come right up to the membrane, but not pass freely through the membrane. Because of the lipid bilayer, water molecules can only pass through protein channels in the membrane. Other molecules that dissolve in water must go through protein channels to move into or out of cells. The lipid bilayer helps control the environment inside a cell, and the proteins of the cell membrane determine which substances can move into and out of a cell through the cell membrane.

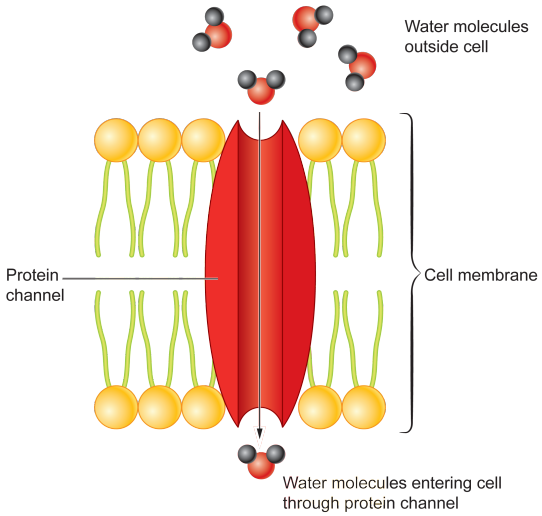


Figure 2.4 Movement of water through a protein channel in the cell membrane.

Mini-Activity

Soap Bubbles Have you ever noticed a swirl of subtle colors on a large soap bubble? This free movement is similar to the movements of molecules within the membrane of a cell. Try the following activities to help you imagine the direction of free movement or the fluidity of proteins and lipids in a cell membrane.

1. Blow soap bubbles in the light and watch the movement of the colors on the surface of the bubbles. Cells allow movement somewhat like this.
2. Straighten a paper clip. Dip the straightened paper clip into a bubble solution. Move the paper clip into a bubble and then across a bubble. What happens? Repeat using many different objects (or your finger).

Also try bubbles of different sizes and see which size bubbles last longest. Try to make elongated bubbles and see if those ever divide into two spherical bubbles. Why do you think that occurs?

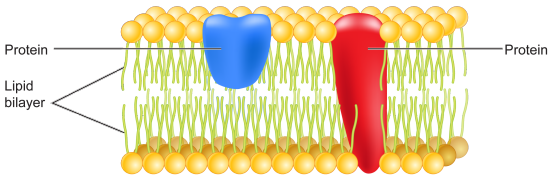


Figure 2.5 Proteins and lipids make up the cell membrane. The proteins have different functions. Some might be receptors for hormone signals. Others might be channels.

Passage through a Cell Membrane

Assume that all factors influencing the movement of molecules are the same except for the molecular size of the substance. If we know the size of the pore opening of the membrane, we can estimate the size of the substances based on their ability to move through the membrane pores.

Journal Writing

Think of a place or building that only allows certain people to enter or leave, such as a ride at an amusement park or a building with security guards at the doors. Describe how that place regulates who can come and go. What criteria do they use? How does this compare to a cell membrane?

Apply Your KNOWLEDGE

Study the table in Figure 2.6. Then answer the following questions.

1. **Substance W is smaller than ? nanometers (nm).**
2. **Substance X is larger than ? nm but smaller than ? nm.**
3. **Substance Y is larger than ? nm but smaller than ? nm.**
4. **Substance Z is larger than ? nm.**
5. **If membranes with different pore sizes were available how could you determine the exact size of substance X?**

Table 3.1:

Membrane	**Pore Size**	**Can substance pass through pore?**			
		W	X	Y	Z
A	1 *nm*	Yes	No	No	No
B	3 *nm*	Yes	Yes	No	No
C	5 *nm*	Yes	Yes	Yes	No

Figure 2.6 This figure shows the abilities of certain substances to pass through pores of different sizes.

Did You Know?

1 *meter* = 100 *centimeters*

1 *centimeter* = 10 *millimeters*

1 *millimeter* = 1,000 *micrometers*

1 *micrometer* = 1,000 *nanometers*

Cytoplasm and Organelles

The cytoplasm and specialized working parts called organelles are inside the cell membrane. The **cytoplasm** is a sea-like fluid that contains water and other chemicals. Some of these chemicals are found throughout the cytoplasm. Some of the chemicals are found just near the cell membrane, around the edges of the cytoplasm. Because the cytoplasm is fluid, the cell can change shape, much like a bag of water changes shape.

The parts of the cell that are organized for specific functions are called **organelles.** The organelles include such structures as the nucleus and the mitochondria. The nucleus contains the genetic material and the mitochondria convert energy. Figure 2.7 shows some of the major organelles of a typical animal cell.

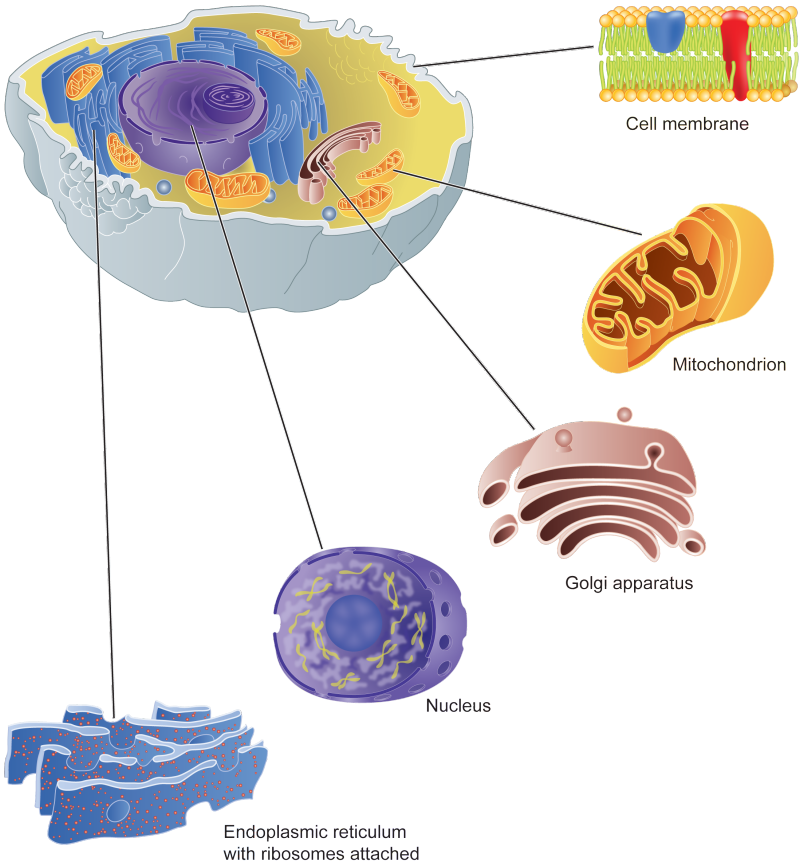
Each of these organelles has a special role to play in the way the cell works. The role of control center goes to the nucleus.

Mini-Activity

What Does Each Part of a Cell Do? Different parts of the cell perform different functions. The cell releases energy or cells make more cells. While you proceed through this section of the text, keep a record of the function of each cell part, or cellular organelle.

Did You Know?

Human cells have nuclei bounded by nuclear membranes and are called *eukaryotes.* (The term *eukaryote* means "true nucleus.") The cells of plants and animals are eukaryotes. Each of their cells has a true nucleus. Some very simple unicellular organisms, such as bacteria and blue-green algae, do not have nuclei. These organisms are called *prokaryotes* instead of eukaryotes. In this unit, we are studying only eukaryotic cells since those are the ones found in your body.



The Nucleus

The **nucleus** is the most important part of a cell. It is the "information" headquarters and is in charge of the cellular activities. It contains the information that will tell the cell what to do, what to make, and when to divide. A nucleus is a small and very powerful part of a cell.

What Do You Think?

Why do you think it would be an advantage for a cell to have a membrane-bound nucleus?

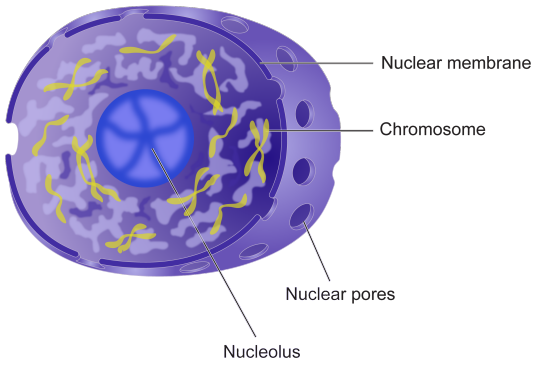


Figure 2.8 The nucleus.

All cells contain genetic material in units called genes. Genes control what a cell looks like, what it can do, and how it functions. In the cells of higher organisms, including humans, the genetic material is found inside the nucleus. A nucleus is a region within the cell that is surrounded by a membrane, called the nuclear membrane. The nuclear membrane controls which molecules enter and leave the nucleus.

Chromosomes

If you looked at one of your cells under a microscope, you would see that under certain conditions, structures called **chromosomes** appear in the nucleus of the cell.

There are 23 pairs of chromosomes in the nucleus of human cells. Of these 23 pairs there are two main kinds-22 pairs of matched chromosomes (autosomes) and a pair of sex chromosomes. Each chromosome is a particular length and has a short arm and a long arm. Besides size and shape, the banding pattern of a chromosome is also distinctive. The chromosomes are not found in any particular order within a nucleus. However, in the laboratory, scientists can sort them into pairs and identify each chromosome, as shown in the diagram.

Each chromosome is made up of two parts-**DNA (deoxyribonucleic acid)** and proteins. The DNA is the genetic material that codes for the characteristics of a person. A chromosome contains one long molecule of DNA.

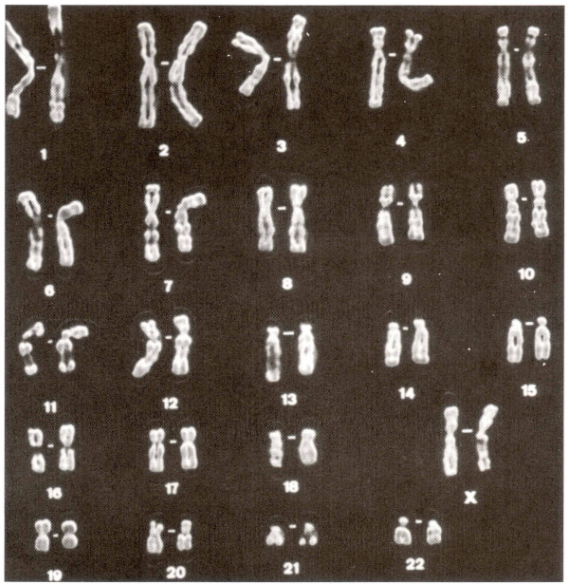


Figure 2.9 Chromosome count of a typical human female. Every cell in a healthy human female has these chromosomes in the nucleus.

Mitochondria

Cells require a continuous supply of energy. **Mitochondria** have the job of converting energy in the food you eat to a form that is usable by cells. Mitochondria are fairly large organelles that look like this:

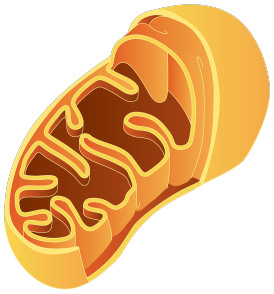


Figure 2.10 Mitochondrion.

Mitochondria are present in the cytoplasm of all cells. In a typical cell the mitochondria might be located randomly throughout the cytoplasm.

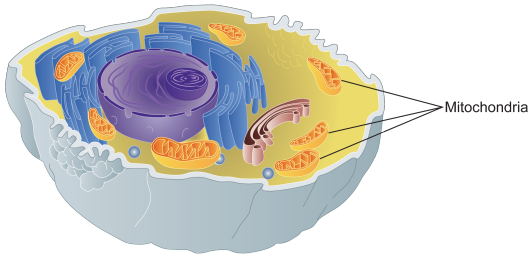


Figure 2.11 Mitochondria within a cell.

Mitochondria make a compound called **adenosine triphosphate (ATP)** from other molecules. When the chemical bonds of food molecules, such as sugar, are broken, energy in the form of ATP is produced. The ATP is then stored in the mitochondria until it is needed elsewhere in the cell.

ATP contains the energy that is used by the cell to make all of its products and to carry out its functions. ATP is like cash. It can be used to make goods and services. There are other forms of energy around the cell, but the cell must convert this energy into ATP to make products that help the cell to live and to function normally.

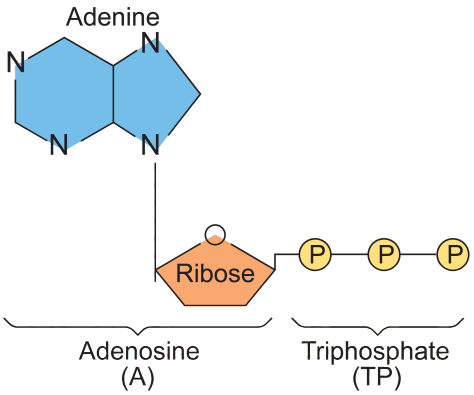


Figure 2.12 ATP structure.

Ribosomes

Proteins are important molecules produced by cells. **Ribosomes** are the organelles where proteins are produced or synthesized. Ribosomes are themselves made up of proteins. The ribosomes are scattered throughout the cytoplasm or are attached to part of another organelle called the endoplasmic reticulum.

Endoplasmic Reticulum

The **endoplasmic reticulum** is a series of folded membranes that is used to move materials around the cell. All cells have endoplasmic reticulum (or ER). The ER also is involved in helping to make different kinds of cell membranes, including the outer (plasma) cell membrane, mitochondrial membrane, and nuclear membrane.

There are two main kinds of ER-rough and smooth. Rough ER has ribosomes attached to it and makes proteins, including many important proteins for the plasma membrane. Smooth ER does not have ribosomes but is involved in modifying proteins synthesized by the rough ER.

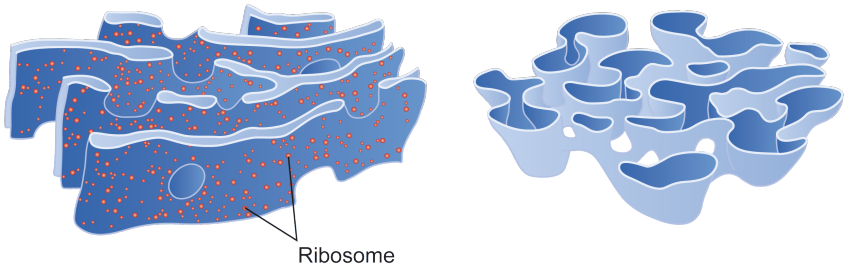


Figure 2.13 Endoplasmic reticulum with ribosomes attached (left). Smooth endoplasmic reticulum without ribosomes (right).

Golgi Apparatus

The **Golgi apparatus** is a series of flattened sacs. When you observe the Golgi apparatus through a powerful microscrope, the sacs appear to lie on top of one another in a stack. The bottom of the stack lies near the nucleus, or part of the rough ER. The top of the stack lies closer to the outer cell membrane. The Golgi apparatus helps sort the proteins synthesized on the rough ER. The proteins are transported to the Golgi apparatus where they may be stored or chemically modified and then packaged for delivery to the

cell membrane for export outside the cell or to other places inside the cell.

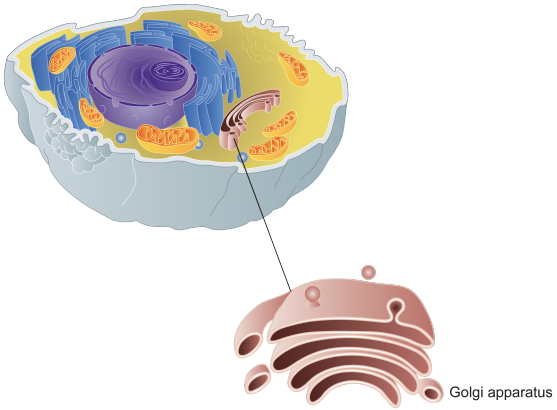


Figure 2.14 Golgi apparatus.

Summary of the Cell Parts

As you look back through this section of the unit, you can revisit the different organelles in the cytoplasm and their functions. Here's a quick review of those organelles.

The **cell membrane,** or plasma membrane, forms a barrier to create an environment inside the cell that is separate from the environment outside the cell. The membrane is a vital border. It controls what enters and what leaves the cell.

The **nucleus** is the control center of the cell that contains the chromosomes with their genetic material, DNA. The nucleus controls all cellular functions.

Chromosomes are large molecules in the nucleus made up of DNA and protein.

Mitochondria are the factory and storage center for ATP, which is used as energy by the cell in making cellular products and carrying out the functions of the cell.

Ribosomes are the sites for protein synthesis.

The **endoplasmic reticulum (ER)** is an elaborate membrane system throughout the cytoplasm. Portions of ER contain ribosomes on the membrane surface.

The **Golgi apparatus** are the flattened sacs that help sort the proteins synthesized by the rough ER and ribosomes.

Apply Your KNOWLEDGE

For each of the cell organelles or parts listed above, explain how each one contributes to the overall internal balance (homeostasis) of the cell to keep it functioning smoothly.

Activity 2-1: Making a Cell Model

Introduction

What do cells in your body look like? What makes up a cell in your body? In this activity you create a model of a cell in your body.

Student Materials

- To be determined by each team, with teacher approval
- Activity Report

Procedure

Step 1 Imagine a cell in your body. What does this cell look like? Complete question 1 on the Activity Report. Draw a picture and label the parts of this cell.

Step 2 What materials would you need to construct a model of this cell? Brainstorm to make a list of materials necessary for making your body cell. Be sure to select materials that will not spoil. After teacher approval of the materials you selected, complete question 2 on the Activity Report.

Step 3 Create your model of a cell using your drawing and approved list of materials.

Step 4 Name and label each of the following parts of your cell model and any other important parts of the cell.

Cell membrane Mitochondria

Cytoplasm Ribosomes

Nucleus Endoplasmic reticulum

Chromosomes Golgi apparatus

For labels, you can use toothpicks and paper flags. Include the name and function on the flag, or simply label the parts of the cell and include the functions of these parts in an accompanying key. Record your name on your model.

Complete question 3 on the Activity Report.

Step 5 Share the model of a cell with your classmates. Note how these models are different from one another. Which model impressed you the most? Why?

Complete your Activity Report.

Review Questions

1. What is the primary function of the cell membrane? Describe three structural characteristics of the cell membrane.
2. What is the difference between a eukaryotic and a prokaryotic cell? Include examples of eukaryotes and prokaryotes.
3. What is the functional relationship among mitochondria, sugar, and ATP?
4. How are ribosomes, the endoplasmic reticulum, and the Golgi apparatus involved in the production and transport of proteins?

Chapter 4

Cell Activities - Student Edition (Human Biology)

4.1 Cell Activities

Human cell.

What are some cell functions?

The life of a cell depends on its environment and on the activities that take place within it. This section explains some of the processes that take place in cells and some of the ways cells respond to their environment.

The functions of all cells depend on or require special molecules called **enzymes.** Enzymes are proteins that help chemical reactions take place. They help cells build products like proteins, make copies of DNA molecules, make energy available for cell work, and even break down certain molecules. Each enzyme is very specific in its action.

Without enzymes, most chemical reactions that take place in cells would proceed very slowly, if at all. Enzymes enable those reactions to happen faster.

Different enzymes exist in different parts of a cell. Enzymes on the surface of a cell help receptor proteins signal the cell when they detect certain molecules in the fluid environment. Enzymes in the cell cytoplasm allow the structural proteins of the cytoplasm to do their work, for instance, to contract, to change the cell shape, or to divide the cell. Enzymes in the nucleus of a cell allow the cell to copy its DNA. Enzymes in the mitochondria of a cell allow the cell to convert energy from food nutrients into ATP.

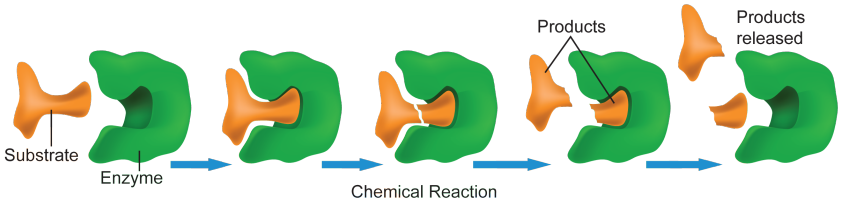


Figure 3.1 The action of an enzyme that breaks down a certain kind of molecule.

Activity 3-1: Catalysts and Enzymes in Your Life

Introduction

How do the many necessary reactions in the cells of your body occur? What helps these reactions maintain homeostasis in your body? How are catalysts and enzymes similar? How are they different? In this activity you investigate the action of the catalyst manganese dioxide (MnO_2) and the enzyme catalase, on hydrogen peroxide. This activity helps you learn more about how chemical reactions occur in your body and what happens when these "facilitators" are absent or do not function properly.

Materials

- Test tubes (5 per team)
- Test tube rack
- Test tube holder
- Marking pen/pencil for test tubes
- Graduated cylinder
- Forceps
- Stirring rod
- Hydrogen peroxide ($H_2O_2 - 3\%$)
- Sand
- Manganese dioxide (MnO_2)
- Wooden splints
- Paper towels
- Goggles for each team member
- Liver cell samples (cooked and uncooked)
- Activity Report
- Data Table

Procedure

Step 1 Design a data table that includes space to write and illustrate the procedure and record observations for test tubes #1-#5.

Part A

How Are a Catalyst and an Enzyme the Same and Different?

Step 2 Label three clean test tubes #1, #2, and #3.

Step 3 Measure and pour 5 *ml* (milliliters) of hydrogen peroxide into each test tube. Be sure to put the cap back on the bottle of hydrogen peroxide.

Step 4 Use a wooden splint to place a small amount of sand into test tube #1. Observe what happens and record your observations in your data table.

Step 5 Use a wooden splint to place a small amount of manganese dioxide MnO_2, into test tube #2. Observe what happens and record your observations in your data table.

Step 6 Obtain a sample of uncooked liver. Use the forceps to place the sample of uncooked liver into test tube #3. Observe what happens and record your observations in your data table. ***Save test tube #3 for use as your control for each test in Part B.***

Step 7 Complete questions 1-5 on the Activity Report.

Part B

What Affects Enzyme Action?

Step 8 Label two clean test tubes #4 and #5.

Step 9 Measure and pour 5 *ml* of hydrogen peroxide into each test tube. Be sure to put the cap back on the bottle of hydrogen peroxide.

Step 10 Obtain a sample of cooked liver. Remember that cooking the liver causes the temperature of the liver to become very high for a period of time. Use the forceps to place the sample of cooked liver into test tube #4. Observe what happens and record your observations in your data table.

Step 11 Obtain a sample of liver soaked in vinegar. Remember that vinegar is an acid, although not as strong as the acid in the digestive juice in your stomach. Use the forceps to place the sample of liver soaked in vinegar into test tube #5. Observe what happens and record your observations in your data table.

Step 12 Complete the remaining items on the Activity Report.

Mini-Activity

Transport of Nutrients: Exploring Diffusion Answer the following questions in writing.

- What do you think would happen if you filled a small beaker with tap water and added one drop of food coloring?
- What would happen if you filled a small beaker with tap water and added a cube of sugar?
- How is diffusion affected by temperature?
- What happens when someone opens a container of perfume or uses a spray bottle of room deodorizer?

Design your own activity to explore one of these questions. Then, answer this question.

How is the diffusion described here like the diffusion of nutrients and wastes in your cells?

Cell Transport

You learned earlier that the cell membrane controls what goes into and out of the cell. Some of the proteins in the membrane act as channels that allow certain molecules to move across the membrane. Some of the protein channels can be open or closed at different times. Other proteins in the membrane act as "pumps" that transport molecules across the membrane. Still other proteins act as "receptors" that signal to the cell when certain types of chemicals are present in the fluid outside the cell. Because the cell membrane is permeable to some molecules and not to others, it is called a semipermeable, or selectively permeable, membrane.

Diffusion is the random movement of molecules from a region of higher concentration to a region of lower concentration. Diffusion will continue as long as there is a difference in the concentration of molecules.

When diffusion stops, a state of equilibrium is reached and the concentration of the molecules is equal throughout the given system.

Osmosis

The semipermeable membranes of most cells allow water to pass through, but not many of the molecules dissolved in water, which are called solutes. When a membrane is permeable to water but not to the materials inside a cell, water molecules will move from where there is a lower solute concentration to where there is a higher solute concentration. Let's see how this movement of water affects cells in your body. Think about your red blood cells. They are round discs that look like doughnuts without holes. If you put some of your red blood cells in fresh water from the faucet, the red blood cells will swell up and form little balls. Some or all may burst. This happens because the solute concentration inside the cells with all the dissolved proteins and other substances in the cytoplasm is greater than the solute concentration in the tap water. The process whereby water moves across a semipermeable membrane (such as the cell membrane) because of differences in solute concentration on the two sides is called **osmosis.** The red blood cells will swell and burst because water from the faucet has fewer materials dissolved in it than the contents of the cell. In contrast, seawater has more materials (such as salts) dissolved in it than the cell contents. If you put red blood cells in seawater they lose water and shrink and shrivel.

> **What Do You Think?**
>
> Considering what happens to red blood cells in different environments, describe what you think would happen if you moved a single-celled organism from its normal freshwater pond to a saltwater environment. What about moving a saltwater single-celled organism to fresh water? Explain.

Passive and Active Transport

Diffusion and osmosis are examples of **passive transport.** Passive cell transport is the result of differences in concentration and the random motion of the molecules. Passive transport does not require the cell to use any energy to move molecules.

In **active transport** the materials move from a region where they are in a lower concentration to a region where they are in a higher concentration. This is an "uphill" process that requires the cell to do work. The cell must provide energy to do this work. The energy comes directly from adenosine triphosphate (ATP). A good example of active transport is what happens at the cell membrane of a nerve cell. The concentration of charged potassium ions ($K+$) is maintained in a higher concentration on the inside of the nerve cell membrane. The concentration of charged sodium ions ($Na+$) is maintained in a higher concentration outside the nerve cell membrane. Because of these differences in concentration, potassium tends to leak out of nerve cells and sodium tends to leak in. However, ion pumps in the cell membrane are always using ATP to power their pumping of potassium ($K+$) into the cell and not out of the cell. This active transport is very important in order for a nerve cell to send an electrical nerve impulse.

> *Journal Writing*
>
> You and your best friend are in a canoe on a river. Describe the effort you put in to get the boat to move with the current. Suddenly you realize you forgot something on the shore, so you tum around and paddle upstream. Describe your efforts to move against the current. How is this scenario like active and passive transport? Explain.

Cellular Respiration

In the previous section you learned that the mitochondria are factories and storage centers for ATP. An active cell requires millions of molecules of ATP every second to carry out its activities. Cells make the

ATP they need using oxygen and glucose in a process called **cellular respiration.** Glucose is broken down through a series of enzymatic reactions. Cellular respiration produces ATP, as well as carbon dioxide and water.

The overall equation for cellular respiration is summarized below:

$$\underset{\text{Glucose}}{C_6H_{12}O_6} + \underset{\text{Oxygen}}{6\ O_2} \xrightarrow{\text{enzymes}} \underset{\text{Adenosine Triphosphate}}{36\ ATP} + \underset{\text{Carbon Dioxide}}{6\ CO_2} + \underset{\text{Water}}{6\ H_2O}$$

The cell cannot use glucose as a direct source of energy. An analogy might be the gasoline in the gas tank of a car. If all the gasoline were burned at once, the car would explode. Instead only a small amount is supplied to the engine where controlled burning takes place. The same is true for cells. The energy from glucose is used in small amounts to synthesize or make molecules of ATP, as shown above.

What Do You Think?

Why do you think it is so important for living things to reproduce and pass on their genetic material? Why is this "the purpose of life"?

The Cell Cycle

Of all the important things that a cell can do, the most important is to reproduce itself by dividing. Reproduction is an essential function of a living system. Each cell, each animal, and each plant will die and its genetic information will cease to exist if it does not copy (replicate) itself. Cell reproduction occurs when a single cell divides into two daughter cells.

The term *daughter cell* may seem unusual to you because human daughters are not true copies of their mothers. *Daughter cells* is a term that scientists use when they write about the process of cell division or mitosis. The reason that human daughters aren't the same as their mothers has to do with the other kind of cell division, meiosis, the kind that only occurs in the reproductive organs of males and females.

When a cell prepares to divide and actually goes through division, we say that it is cycling or going through the **cell cycle.** Most of the cells in our bodies can divide to replace themselves or, if necessary, divide to replace neighboring cells of the same type that are dying. Many cells only live for days or weeks, so certain cell types in our bodies are always dividing to replace those that are being lost. At any one time, some cells (such as those of our bone marrow, hair, skin, and intestine) are dividing more frequently than other cells (such as those in our muscles and our brain).

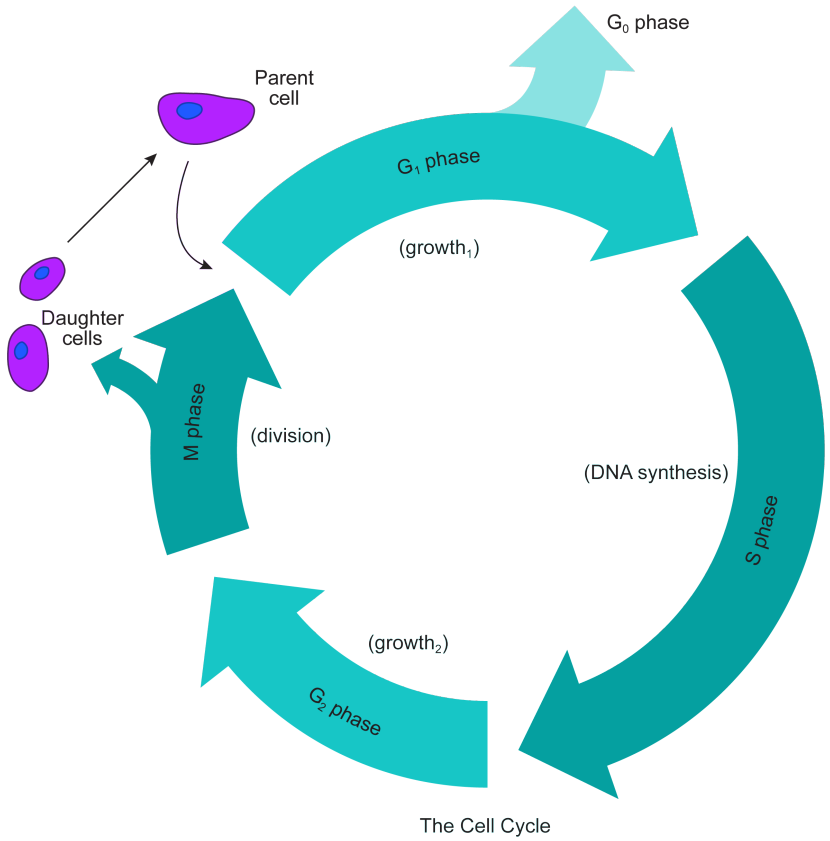


Figure 3.2 The cell cycle.

When animals grow, their cells must divide rather than just get bigger. Cells divide because there is a size beyond which they cannot work efficiently. Remember the relationship between the surface area and volume of a cell. Necessary materials must move into cells to provide energy, and wastes must be carried out of cells. When the cell grows beyond a critical size, this efficiency is decreased. As a result, the cell divides into two smaller daughter cells that are more efficient in carrying out cellular processes. So tissues and organs grow by adding new cells through cell divisions.

The cell cycle is a repeating cycle of growth and division that consists of four main phases. These phases are called G_1, S, G_2, and M. Collectively the G_1, S, and G_2 phases are known as the interphase stage of the cell cycle.

During the G_1 phase, a cell grows and carries out its basic functions. This phase makes up a major portion of the cell cycle.

During the S phase, the cell's DNA is copied or replicated.

During the G_2 phase, the cell prepares for the division of its nucleus. Proteins and membranes are made.

Finally, during the M phase, mitosis, or cell division takes place. Two nuclei are created, each with the same number of chromosomes.

At any given time, most of our cells are not actively dividing or cycling. Instead they are resting. We call the part of the cell cycle where cells are resting the G_0 phase. Most of your cells are resting in G_0 right now. Some of your cells, stem cells, and many cells of your intestine, bone marrow, and hair follicles may be cycling. There are different signals a cell may receive that make it cycle. The cell may get a signal from outside its membrane or from inside the cell itself. Then it will enter the G_1 phase. Once a cell enters G_1 and begins to cycle, it takes about 18 to 24 hours to complete the cycle and form two daughter cells. The

relative duration of the different phases of the cell cycle depends on the species of the organism and the type of cell.

Let's look more closely at how cells divide. How does one cell become two?

Mitosis-Cell Division for Somatic Cells

There are two main categories of cells. The most common cells are the **somatic cells.** These include almost all the cells in your body-the cells that make up the structure of your body and all your organs, such as the brain, heart, muscles, intestine, and liver. The other cells are the **gamete cells**, which are either sperm in males or eggs in females. You can see that almost all cells belong in Category 1-Somatic Cells. Only a few of the many cells in Category 1 are listed.

Table 4.1:

More than 100 kinds of cells Category 1-Somatic Cells	**Only two kinds of cells Category 2-Gamete Cells**
Lens cells	sperm
Iris cells	eggs
Skeletal muscle cells	
Heart muscle cells	
Pancreatic cells	
Lung cells	
Immune system cells	
Blood cells	
Nerve cells	
Skin cells	
Liver cells	
SOMATIC CELLS DIVIDE ONLY THROUGH MITOSIS.	GAMETE CELLS DIVIDE THROUGH MEIOSIS.

Somatic cells all go through the same kind of cell division. This process is **mitosis**, which is the M phase of the cell cycle. The parent cell reproduces into two daughter cells as a result of division of the chromosomes and division of the cytoplasm. All our cells, except our gamete cells, are produced only through the process of mitosis. The gamete cells are produced through a process called meiosis.

Figure 3.3 A parent cell divides into two daughter cells.

Mitosis involves making exact copies of the parent cell. If the daughter cells are exact copies of the parent cell, what does this mean in terms of chromosomes? Let us look first at the overall process. How many chromosomes does the parent cell have? Remember each somatic cell is diploid which means double-it has two sets of each of the 22 autosomes and a pair of sex chromosomes. If the daughter cells are each exact copies of the parent cell, then how many chromosomes must they each have? The answer is, "The daughter cells each have the same as the parent-two sets of each of the chromosomes, or 46 chromosomes in each

diploid cell."

How can the parent cell become two daughter cells with each of these cells having the same identical number of chromosomes? If you guessed that the parent cell must duplicate its chromosomes, you guessed correctly. To duplicate each of its chromosomes, the parent cell must go through DNA synthesis or the S phase of the cell cycle.

Each of the new daughter cells is just like the parent cell. The process of mitosis proceeds with remarkable accuracy. In the end, the number of chromosomes per cell remains the same. The parent cell was diploid and each daughter cell is diploid, as well.

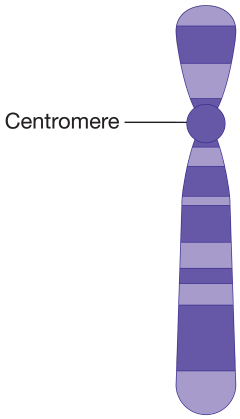


Figure 3.4 Diagram of a chromosome before it is duplicated.

Figure 3.5 Diagram of a duplicated chromosome.

In Activity 3-2, you will investigate the process of mitosis. Figure 3.7 below shows the steps in this process.

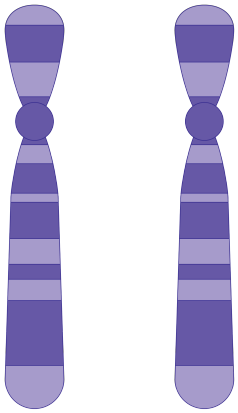


Figure 3.6 Diagram of the separated chromosome from Figure 3.5. The two daughter chromosomes become separated (at the centromere) during cell division. Each daughter cell gets two sets of 23 chromosomes. Each of these is just one of those 46 chromosomes.

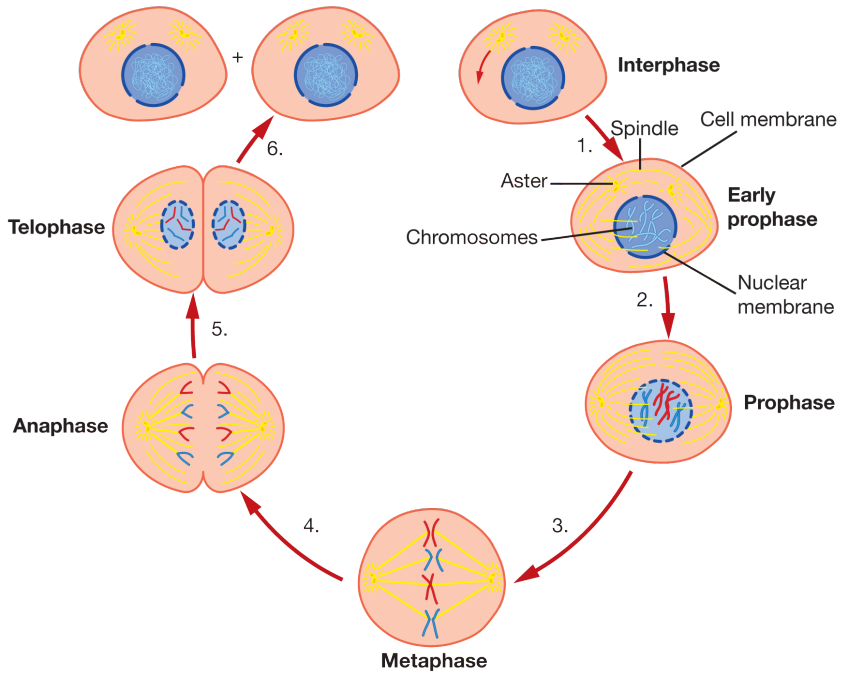


Figure 3.7 The process of mitosis involves division of both nucleus and the cytoplasm. Mitosis can be divided into 4 stages-prophase, metaphase, anaphase, and telophase. When the cell is not in the process of cell division, it is in interphase.

1. DNA replicates.
2. Chromosomes become compact. Aster and spindles form.
3. Nuclear membrane breaks down. Chromosomes line up.
4. Centromeres divide. Duplicated chromosomes move to opposite sides.
5. Cytoplasm is divided. Nuclear membrane reforms.
6. Cell divides. Chromosomes become less compact.

Activity 3-2: Cell Division-Double or Nothing

Introduction

Many-celled organisms, including yourself, begin as a single cell. What is the process of producing millions of cells from a single cell? In this activity you explore how a cell reproduces (divides) to form two new cells. Mitosis is a continuous and orderly process that occurs in your body's somatic cells. In this activity you model each stage of mitosis using pipe cleaners to represent chromosomes.

Materials

- Resources 1 and 2
- Activity Report
- Colored crayons or colored pens or pencils (same colors as pipe cleaners if possible)
- Large paper plates (2)

- Eight pipe cleaners, (2 long of color A, 2 long of color B, 2 short of color A, and 2 short of color B)

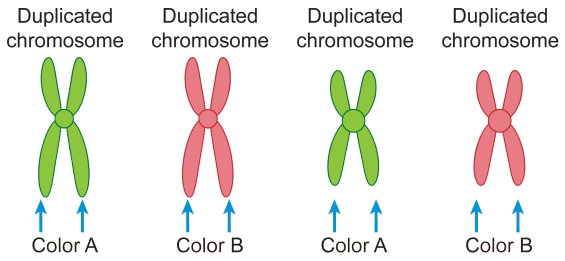


Figure 3.8 One long and one short pair, Color A. One long and one short pair, Color B.

Procedure

Step 1 Gather four pairs of pipe cleaners to represent the chromosomes. Remember that your somatic cells have 23 pairs of chromosomes. Here we follow two pairs of chromosomes through the process of mitosis.

Step 2 Arrange your pipe cleaners so each pipe cleaner in the pair is of the same length and color. Twist each pair together by one turn at the midpoint. Each pair of pipe cleaners represents a duplicated chromosome. The two different colors indicate that one chromosome came from the father and one came from the mother. Duplicate chromosomes are formed through the process of DNA replication, which occurs before mitosis begins.

Step 3 Take two plates and place one plate on top of the other. The plates represent a cell. Put your chromosomes on the top plate. Using the crayons, draw a picture of the chromosomes on your Activity Report.

This phase (prophase) can be recognized when the double chromosomes are visible and can be observed under the microscope as distinct bodies.

Step 4 Line up the double chromosomes along a line that divides the top plate into two halves. Using crayons or colored pencils, draw a picture of the chromosomes on your Activity Report.

During this phase (metaphase) the chromosomes line up in the middle of the cell.

Step 5 Now separate each double chromosome by untwisting them. Leave them side by side on the midline through the center of the plate. Next move one single chromosome of each pair to the left of the plate and one to the right. Each chromosome is now a single chromosome, and each side of the plate should have two long and two short single chromosomes.

This phase of mitosis (anaphase) occurs when double chromosomes separate into two single chromosomes that move to opposite sides of the cell.

Step 6 Now it is time for the cell to divide into two daughter cells. You represent this step by bringing out the second plate and moving one set of single chromosomes to it. Each newly formed daughter cell has an identical set of chromosomes-two short and two long chromosomes.

In this phase of mitosis (telophase), the cytoplasm divides, resulting in two daughter cells. Each newly formed daughter cell has a nucleus containing a complete set of chromosomes, two sets of the 23 different chromosomes found in the cell. On your Activity Report record a colored drawing of the chromosomes placed on each plate.

Step 7 In the next phase of mitosis (interphase) the chromosomes lose their compact appearance. The chromosomes replicate their DNA so that each single chromosome becomes a duplicated chromosome as you saw in Steps 1 and 2 of the activity.

Step 8 Discuss with your partner the questions on the Activity Report and then record your responses.

Mini-Activity

Mitosis in Action Summarize what you have learned about mitosis by completing one of the following creative activities to share with your classmates.

- Cartoon story
- Poster
- Story book, with drawings
- Poem
- Song
- Dance
- Build models

Meiosis-Cell Division to Produce Egg and Sperm

Meiosis is a special kind of cell division for the two types of cells that unite to make a zygote, which is a fertilized egg. As you read earlier, these two kinds of cells are called gametes. The gamete cells are the sperm in males and eggs in females. The two kinds of gamete cells must fuse at fertilization to form a fertilized egg. The fertilized egg has two sets of chromosomes and is diploid, so each of the gamete cells had only one set of chromosomes instead of two. The sperm brings in one set of chromosomes, and the egg brings in the other set of chromosomes. Meiosis is necessary for gamete cells to be produced, and then unite to form a fertilized egg that will develop into a new individual. How does meiosis happen in humans?

Typically, each of the somatic (body) cells in a human has 46 chromosomes in the nucleus. Remember that this number, 46, represents two full sets of our 23 chromosomes and is called **diploid**. The only exception to this rule is the gamete cells, which have 23 chromosomes and are called **haploid** for half. The gamete cells are produced through two cell divisions, which result in four daughter cells that are each haploid in chromosome number. Figure 3.9 on the next page shows you the process of meiosis by following one pair of homologous chromosomes. You can follow the changes in chromosome number to see how one diploid cell becomes four haploid gamete cells.

What Do You Think?

Some single-celled organisms such as an *amoeba* can reproduce through mitosis only. Why might this process be a good way to pass on their genetic material to their offspring? What might be some problems with this method of reproduction?

Once in a while there are mistakes in meiosis and one gamete cell ends up with an extra chromosome, or another gamete cell could be missing a chromosome. If either one of these abnormal gamete cells (such as the egg) were to unite with a sperm to form a fertilized egg, the developing fetus may not be able to survive, or the individual born could be affected by a genetic disorder. The outcome depends on which chromosome was involved and whether or not there is an extra copy of it, or a missing copy. For example, people born with Down syndrome have an extra copy of chromosome 21 in their cells. That happens because one of the gamete cells (the sperm or egg) that forms these individuals carries two copies of chromosome 21, instead of one copy. People affected with Down syndrome have three copies of chromosome 21 in their cells. Despite the errors that occur, meiosis overall is amazingly accurate when you think about how complicated the process is.

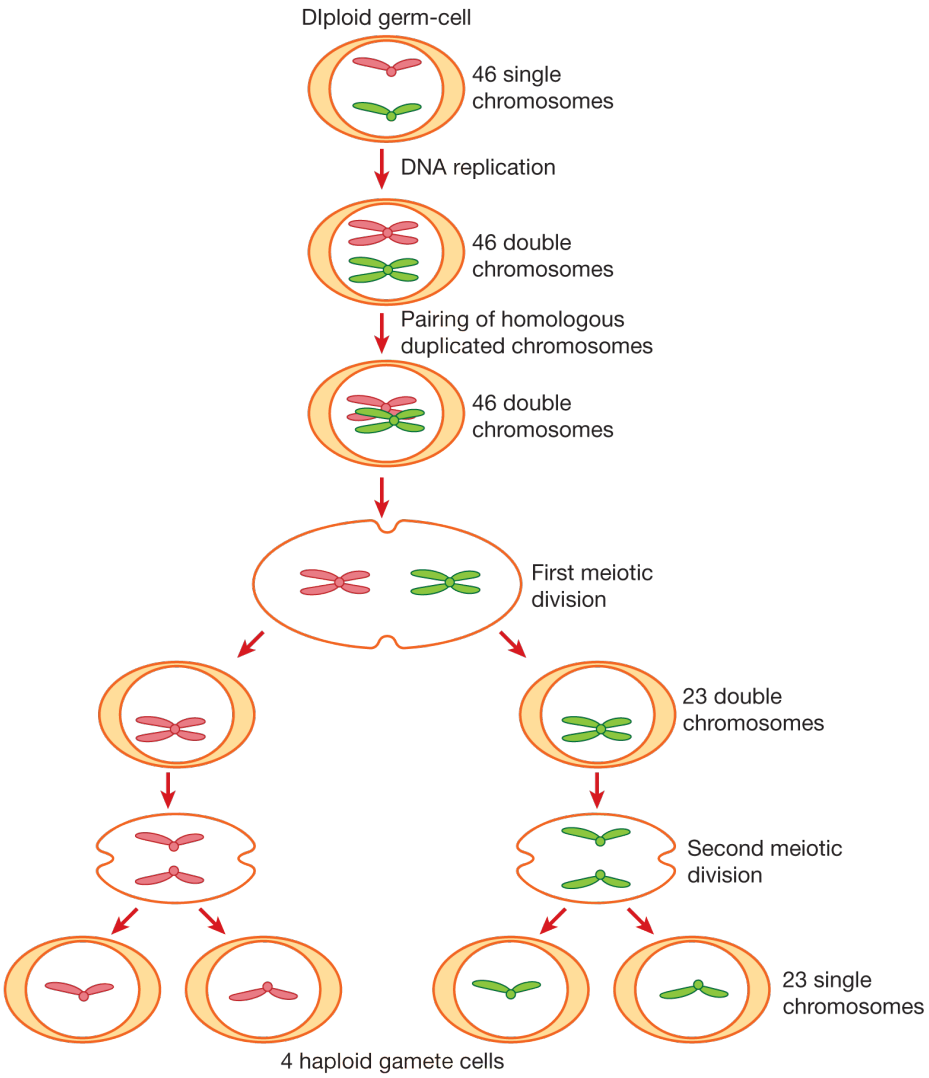


Figure 3.9 Meiosis. One pair of homologous chromosomes is shown inside the cell. The changes in the chromosome number is shown to the right for each stage of meiosis.

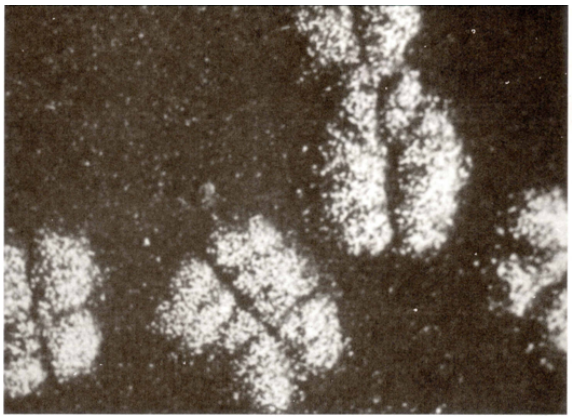
Review Questions

1. What are enzymes and why are they important to the cell?
2. What are the roles of osmosis and diffusion in the cell?
3. Why do cells divide?
4. How are mitosis and meiosis similar? How are they different?

Chapter 5

DNA and the Genetic Code - Student Edition (Human Biology)

5.1 DNA and the Genetic Code



Human chromosomes.

How important is DNA in the functioning of a cell?

Where do cells store the information to do all of the things they do? You probably know the answer to that question-in their DNA. But, do you know how information is organized in DNA? That is what you will learn about in this section. You also will learn how that information is copied accurately so that daughter cells get exactly the same information the parent cell has.

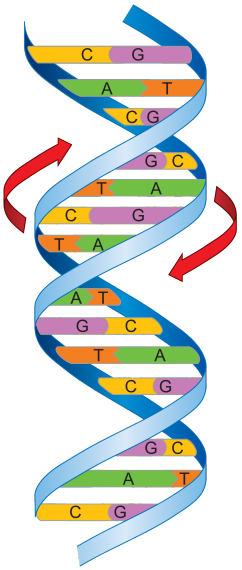


Figure 4.1 Nucleotides are joined together one after the other and form a helix chain. Two of these chains pair and then twist to form a **double helix**, which means "two-chained coil."

DNA consists of repeating molecular units called **nucleotides**. Each nucleotide has three parts-a sugar, a phosphate, and a nucleotide base. There are four different nucleotide bases. The names of the four nucleotide bases are *adenine* (A), *thymine* (T), *guanine* (G), and *cytosine* (C). From now on, we will just use their initials: A, T, G, C. The DNA alphabet that codes for all of the information in DNA consists of only four letters corresponding to the four nucleotide bases. By stringing the nucleotides together in different sequences, the DNA stores information like strings of letters form words that store information.

The DNA molecule consists of two parallel strands of nucleotides. These two strands are twisted around each other to form a **double helix.** Think of a ladder made of flexible plastic. If you twisted that ladder, you would have a double helix. The rungs of the ladder consist of pairs of nucleotide bases, and the sides of the ladder consist of repeating sugar (deoxyribose) and phosphate groups. The pairs of nucleotide bases are not all of the possible combinations of A, T, G, C, however. Nucleotide base A can pair only with T, and G can pair only with C. This pairing is very important for the process by which the DNA molecule copies itself to produce identical copies.

Activity 4-1: Removing DNA from Thymus Cells

Introduction

What does DNA look like? Where is it found in the cell? How can DNA be removed from a cell so we can see it?

In this activity you answer these questions by treating cells so you can remove DNA. You use thymus cells from an animal whose thymus cells are similar to human thymus cells.

Materials

- Sample of fresh thymus cells in a beaker
- Sand
- Liquid soap, clear in a beaker
- Alcohol
- Water, in a beaker

- Cheesecloth square (several layers, 15×15 *cm*)
- Mortar and pestle
- Test tube
- Small funnel
- Test tube rack
- Wooden skewer
- Forceps
- 2 eyedroppers
- Permanent marking pen
- Paper towels
- Black construction paper, 4×4 *cm*
- Transparent tape
- Microscope, slides, and cover slips
- Safety goggles
- Activity Report

Procedure

Step 1 Obtain equipment for your team and arrange it at your lab station.

Step 2 Using forceps, place a sample of thymus tissue in the mortar (bowl). Add a pinch of sand and one to two droppers full of water. Use the pestle to grind the thymus well, adding a little more water as necessary to make a thick, souplike mixture. Answer question 1 on your Activity Report.

Step 3 Put a test tube into a test tube rack and place a small funnel into the test tube. Spread a cheesecloth square over the large opening at the top of the funnel.

Step 4 Carefully pour the thymus contents of your mortar into the cheesecloth square and allow the liquid to filter through the cheesecloth and funnel. Carefully draw together the edges of the cheesecloth and use the forceps to help squeeze the remaining liquid from the thymus mixture. Now discard the cheesecloth and its contents into a special waste container, as indicated by your teacher.

Step 5 Take a drop of the thymus cell liquid from the test tube. Place it on a microscope slide, and put a cover slip carefully on top of the drop. Observe the slide under a microscope and draw what you see on your Activity Report. Add labels, if possible. Answer question 2.

Step 6 Add three to four drops of liquid soap to the liquid in your test tube. Carefully hold the test tube in one hand and tap gently on the bottom of the tube to mix. Answer question 3 on your Activity Report.

Step 7 Mark the level of the liquid in the test tube with a permanent marker.

Step 8 Tilt the test tube and slowly trickle an equal volume of alcohol down the inside of the test tube. Wait 30 to 60 seconds and carefully observe to see what happens at the interface (where the alcohol and thymus mixtures meet). Answer question 4 on your Activity Report.

Step 9 Place a wooden skewer in the test tube and twirl it. Carefully observe what happens as you twirl the skewer. What is wrapping around the skewer is DNA! Keep twirling the skewer until there is no further change. Answer question 5 on your Activity Report.

Step 10 Remove the skewer. Place the skewer on a paper towel and carefully blot it dry. Observe the DNA. What does it look like? How does it feel when you touch it? Record your observations on your Activity Report.

Step 11 Using clean, dry forceps, carefully remove the DNA from the skewer and place it on a small piece of black construction paper. Use clear tape to cover your specimen to keep it from drying out and to fasten it onto the construction paper. Attach the paper to your Activity Report in the space provided. Complete question 6 on your Activity Report.

Step 12 Wash and dry all the glassware you used during the investigation. Store the materials appropriately.

Step 13 Design an alternative procedure to explore different ways of removing thymus DNA, such as using different soaps or different types of alcohol. Record your ideas on the Activity Report. Share your experimental design with your class. Answer question 7 on the Activity Report.

Step 14 How would you modify your experimental design to use different sources for DNA? Which sources would you choose and why? Record your proposals on the Activity Report. Answer question 8.

How the Information in DNA Is Copied

A cell must copy its DNA before it can undergo cell division. This process is called **replication**. Replication is a complex job that must be done quickly. You might wonder just how quickly. Remember that a chromosome is one long DNA molecule. An average human chromosome may consist of 150 million nucleotide sequences. Remember the S phase of the cell cycle is the time over which replication takes place, and it lasts about six hours. So, how many sequences per second have to be replicated to copy an average human chromosome during the S phase?

What Do You Think?

What other processes use templates to produce a copy of something?

During replication, the DNA molecule starts to unwind at one end. An enzyme called a **helicase** helps it unwind. As the DNA molecule unwinds, the double strand splits right down the center, between the nucleotide base pairs forming two templates for DNA replication. The now unpaired nucleotide bases are free to combine with new partners. But, since a nucleotide base A can only combine with a *T*, and a *C* can only combine with a *G*, each strand combines with only the correct nucleotides to accurately recreate its complementary strand. Special enzymes carry out this neat and orderly replication process. These enzymes are called **DNA polymerases**.

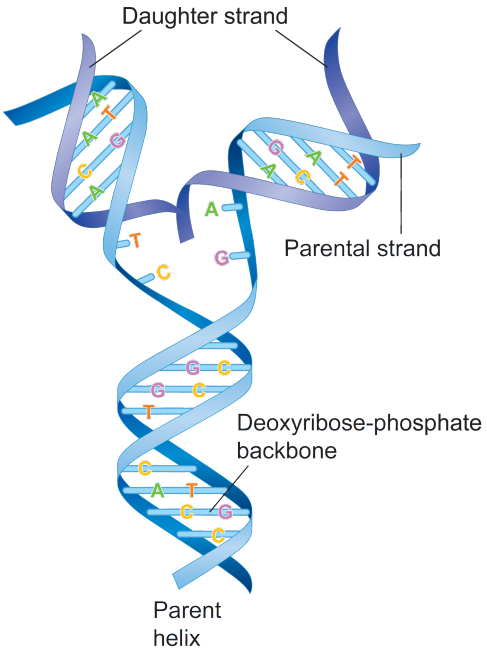


Figure 4.2 Parental strands unwound. This picture shows a double helix. It is opened at the top to allow the DNA to be copied.

The DNA polymerases can only read the template DNA strand in one direction. Since the two strands of a DNA molecule run in opposite directions, the replication process is not the same on the two strands as the DNA unwinds. On one side, the DNA polymerase moves smoothly along the strand as the DNA unwinds and splits. This strand is called the continuous or leading strand. On the other side of the split, however, the DNA polymerase starts the process near the unwinding point and moves up the strand in the opposite direction. This strand is called the discontinuous or lagging strand. It has to have its gaps filled in by other enzymes before it is an exact copy of the original DNA molecule.

Now look at how this process occurs. In Figure 4.3, you can see the direction that the DNA polymerases work on the template DNA strands. Arrows show the direction of synthesis. Note on one side, replication proceeds "down" the strand; on the other strand, it proceeds up.

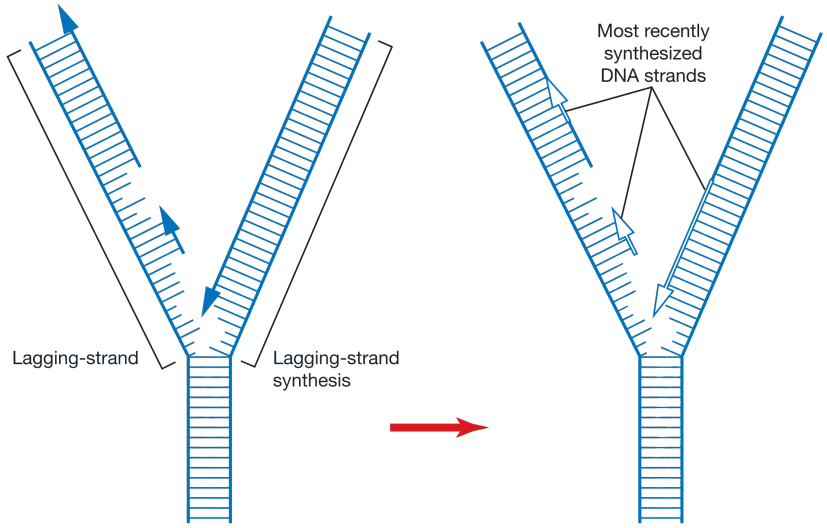


Figure 4.3 DNA synthesis in progress showing leading and lagging strands.

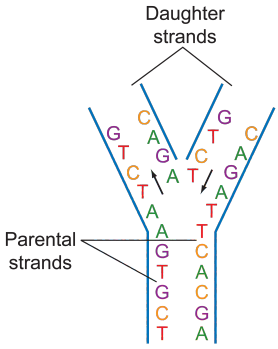


Figure 4.4 DNA is copied in this way. The exact nucleotide base sequence is copied in the direction shown by the arrows. The double helix is opened at the top of the diagram. Then each correct nucleotide base is added in exactly the right order. Perfect copies of the DNA sequence are made. Each chromosome is one long double helix DNA molecule. So this diagram shows how each chromosome is copied during cell division.

The DNA polymerase also checks its own work. It proofreads the new strand as it is made to make sure that all of the new nucleotide base pairs are correct. If a wrong nucleotide base is added to the growing strand, the DNA polymerase will cut it out and try again.

Activity 4-2: Building and Using a DNA Model

Introduction

How do nucleotides fit together to make a DNA molecule? What does this double helix molecule look like? In this activity you will make a model of DNA and a copy of your model to learn more about the structure and function of DNA and how it replicates.

Materials

- Resource
- Activity Report
- Scissors
- 6 different sets of colored paper
- Tape

Procedure

Part A-A DNA Model

Step 1 Working in pairs, cut out pieces from the template for each of the following.

A-adenine, red

C-cytosine, yellow

T-thymine, blue

G-guanine, green

P-phosphate, orange

D-deoxyribose (sugar), white

Your task is to make a total of 60 nucleotides:

15 adenine nucleotides containing the nitrogen base adenine;

15 cytosine nucleotides containing the nitrogen base cytosine;

15 thymine nucleotides containing the nitrogen base thymine; and

15 guanine nucleotides containing the nitrogen base guanine.

Make an **adenine nucleotide** by taping together one adenine nitrogen base, one deoxyribose sugar, and one phosphate. Make 14 more adenine nucleotides.

Make 15 **cytosine nucleotides.** Each cytosine nucleotide is made of one cytosine, one deoxyribose sugar, and one phosphate. Tape the three parts of each cytosine nucleotide together.

Make 15 **thymine nucleotides.** Each thymine nucleotide is made of one thymine, one deoxyribose sugar, and one phosphate. Tape the three parts of each thymine nucleotide together.

Make 15 **guanine nucleotides.** Each guanine nucleotide is made of one guanine, one deoxyribose sugar, and one phosphate. Tape the three parts of each guanine nucleotide together.

Step 2 Build a ladder consisting of 12 nucleotide pairs. Do not use more than 7 individual adenine, guanine, cytosine, or thymine nucleotides that you made. Tape the nucleotides together. Remember that adenine pairs with thymine and cytosine pairs with guanine. Save the remaining nucleotides for Part B.

Step 3 Hold both ends of the model and gently twist. You have made a "double helix."

Step 4 Answer questions 1 through 5 on the Activity Report.

Part B-Replication

Step 5 Gently untwist your DNA model from Part A and place it in front of you. Separate the two halves of your model by cutting between the nitrogen bases (A & T and C & G).

Step 6 Using the extra nucleotides you saved from Part A, add nucleotides to each of the DNA halves. Remember that adenine. bonds (connects) with thymine and cytosine bonds with guanine. Answer questions 6 and 7 on the Activity Report.

Why DNA Is Important

Now you know how DNA codes for information and how that information is replicated so that each daughter cell gets exactly the same set of DNA instructions. Now let's discover the answers to these questions: How does the DNA code get used or expressed in a cell? What information is in this set of blueprints? How is the information put to work to make a cell do the things that it does?

Different regions of the DNA strand have different ways of influencing how a cell will do its work. Specific regions of the DNA called **genes** code for the production of specific proteins. These proteins are responsible for specific products and functions characteristic of the particular cell type. For example, muscle cells in your arm are different from nerve cells in your brain, yet both kinds of cells have the same DNA. The muscle cell and the nerve cell just use different portions of the DNA. They express different genes to make their specific protein products that carry out the specific functions of each cell type.

Proteins consist of chemicals called **amino acids.** The amino acids are bound together in long chains called polypeptides. You could think of amino acids as the alphabet that makes up the protein molecule. Proteins are produced when amino acids are added one by one at the ribosomes. The amino acid sequence of a protein gives that protein its character. The DNA code for a particular protein is stored in your genes.

Now you might realize that we have a problem based on cell structure. The DNA information is in the nucleus. But, the proteins are made at the ribosomes in the cytoplasm. Therefore, the blueprints are in the nucleus, but the protein factory is in the cytoplasm. So how do the ribosomes know how to make proteins? How does the genetic information flow from the nucleus to the cytoplasm of the cell?

The key to this problem is another type of nucleic acid called **messenger ribonucleic acid (mRNA)**. Ribonucleic acids (RNA) are similar to deoxyribonucleic acid (DNA), but a little different in composition and shape. First, the sugar in RNA is different. It is ribose instead of deoxyribose. Second, RNA has a small difference in its nucleotide base alphabet. RNA uses the nucleotide base uracil (U) instead of thymine (T). U pairs with A in an RNA molecule. Whenever a gene is to be "expressed"-meaning that the protein for which it codes is to be made-its information is copied from the DNA gene as a messenger RNA (mRNA) molecule. The mRNA molecule then moves out of the nucleus into the cytoplasm and then to the ribosomes where it provides the information for making the protein molecule.

Transcription-Making Messenger RNA

The process of making a messenger RNA molecule from a segment of DNA is called **transcription**. Transcription is similar to replication. First, the DNA has to unwind, but unlike in replication, only the segment that corresponds to the gene to be transcribed unwinds. Then an enzyme, this time **RNA polymerase**, makes a complementary messenger RNA molecule from the DNA template.

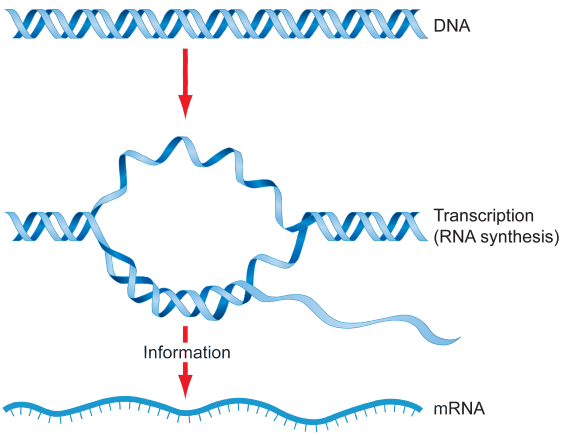


Figure 4.5 Transcription of messenger RNA from the DNA template.

Let us look at the way transcription works. Suppose there is an original DNA sequence that looks like this:

DNA ATGCCGTGAA

It is transcribed to a complementary RNA sequence like this:

RNA UACGGCACUU

When a segment of DNA unwinds and the two strands separate, the RNA polymerase does not make complementary copies of both DNA strands. Only one strand of DNA contains the right information, or gene sequence, for making a specific protein. The mRNA produced by transcription contains the information for making this specific protein.

The Genetic Alphabet

The unique structure of a protein and the reason it can do a specific job is due to its specific sequence of amino acids. The information brought to the ribosome in the form of mRNA is the blueprint for the specific sequence of amino acids that makes a specific protein.

There is another challenge, however. Each strand of DNA or RNA contains combinations of the four-nucleotide bases, but there are twenty different amino acids that make up all of the proteins in your body. So, how do we use an alphabet of only four letters (A, T or U, C, and G), to write sentences using twenty possible words? Obviously, each word cannot be only one letter. Can each word be only two letters?

How many possible words can you make using four letters, two at a time? Try it and see, but the answer is less than twenty. This means that the minimum word length in the genetic vocabulary must consist of three letters. How many possible words will that allow? The correct answer is sixty-four, which is more than is needed to code for the twenty different amino acids.

Mini-Activity

Coding Use the following code and sequence to decode the secret message.

Code Key:

UUU = a	AUU = i	UCU = p	UGU = x
UUC = b	AUC = j	UCC = q	UGC = y
UUA = c	AUA = k	UCA = r	UGA = stop
UUG = d	AUG = start	UCG = s	UGG = z
CUU = e	GUU = l	UAU = t	
CUC = f	GUC = m	UAC = u	
CUA = g	GUA = n	UAA =v	
CUG = h	GUG = o	UAG =w	

AUGCUGUACGUCUUCAUUGUGAUUUCGCUGUACGUCGUCAUUGUACUAUGA

Scientists did clever and important experiments in the 1950s to break the genetic code. Those experiments proved that the code is based on sets of three nucleotides. Thus, each word in the genetic vocabulary has three letters, or nucleotides. When a DNA sequence of three nucleotides is transcribed into an mRNA sequence of three nucleotides, that sequence codes for a specific amino acid.

Scientists also have discovered that some of the triplet nucleotide sequences are codes for start and stop signals that "tell" the mRNA when to start making a protein and when to stop making it. Each triplet of mRNA nucleotides is known as a **codon**. Some of the different codons instruct the RNA to make the same amino acid, just as some words in the English language have the same meaning even though they are spelled differently.

To learn how a triplet code works, consider the following sentences where each word is only three letters long.

1. THE BAD CAT ATE THE OLD RAT AND THE RED BAT.
2. SHE RAN AND SHE WON.
3. SHE RAN AND GOT HER BAT AND SHE HIT HIS LEG.
4. THE BOY GOT HIS BAT AND HAD FUN AND HIS MOM SAW HIM WIN THE BIG ONE FOR HER AND FOR HIM.

We can compare these examples of sentences with examples of different gene products (proteins) in several ways:

- Each one of the sentences, like each gene, is made up of triplet codes. The genes have triplet codes of nucleotides, and the words in the sentences are each made up of three letters.
- These sentences, like different genes, have different meanings. Each one tells a different story.
- Some of the words appear in more than one of the sentences, just as some amino acids appear in more than one protein.
- Some of the words appear more than once in the same sentence, just as some amino acids appear more than once in a protein.
- Each of the sentences is a different length. Some sentences are short and so are some genes. Some sentences, such as sentence 4, are very long; some genes are very long.

Apply Your KNOWLEDGE

Write a sentence in which each word is made up of three letters, but do not leave spaces between the words, and do not use a period at the end of the sentence. Use the Code Key in the *Mini Activity: Coding*. What rules do you have to use to read this sentence? Explain why RNA polymerase must have start and stop signals. What start and stop signals would make it possible for someone to read your message correctly?

Editing the Message

Has anyone in your class worked on a school newspaper or has anyone visited the offices where a city newspaper is produced? If so, have those students explain the job of the person who is called the editor. Writers almost always write too much, and all of the news that is written as copy will never fit into the newspaper unless it is edited. Parts have to be cut out, segments have to be rearranged, and the pieces that are to be printed have to be joined together in such a way that they make sense. A similar editing process takes place before mRNA leaves the nucleus.

There is usually more information in the DNA than is needed to make the proteins that the cell needs. So, before the mRNA leaves the nucleus, it is cut and spliced so that the message that reaches the ribosomes is different than the one that was transcribed directly from DNA.

Mini-Activity

Building a Protein Model Collect 50 pop beads or linker cubes. If possible, select pop beads having 20 different colors to represent the 20 different amino acids. Use any combination of colored pop beads to make a chain of 50 beads. Check with your classmates to see if anyone else has the same sequence of colored beads. What does this tell you about the number of possible proteins that can be made from 20 different amino acids?

Protein Synthesis

Now let's learn more about protein synthesis, which involves the translation of the mRNA message, and how the process takes place.

The edited mRNA is transported out to the cytoplasm where it travels to the ribosomes. Upon reaching the ribosome, the mRNA binds to it. The ribosome serves as the workbench on which the protein coded for by the mRNA is made or synthesized. But first, the "code" of the mRNA has to be translated.

What does translation mean when you are talking about languages? You might think of protein synthesis as going from one language to another. Since the "alphabet and words" of the mRNA code are different from the "words" of the protein, it is the job of the ribosome to decode the RNA message and translate it into protein.

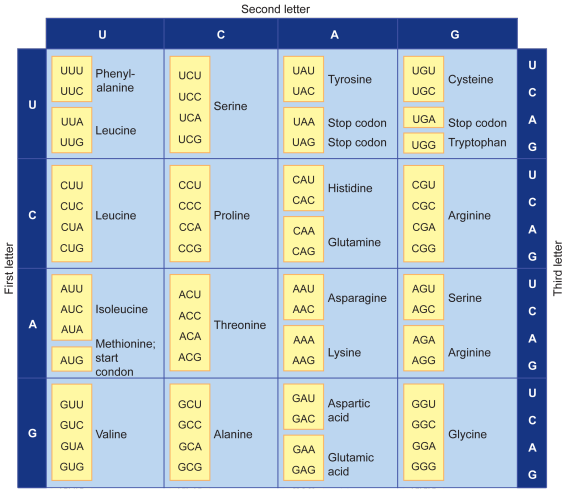


Figure 4.6 Different codons and the amino acids coded by them.

Journal Writing

There are hundreds of different languages spoken around the world. Why do you think there are so many languages? How would you investigate which languages are related to each other? Can you speak more than one language, or would you like to be able to? What are some advantages of being able to speak more than one language?

Figure 4.6 shows the different mRNA codons and the amino acid each codon translates into. For example, the triplet UUU codes for the amino acid phenylalanine (Phe). The triplet GAC codes for Aspartic acid (Asp). The triplet ACU codes for the amino acid Threonine (Thr). Notice different triplets can code for the same amino acid. There are also triplets that code for a STOP signal. This triplet stops the sequence of amino acids when the protein is complete. There is a triplet that means start. It tells the ribosome where to initiate the building of a protein.

More than one ribosome can read the mRNA at the same time, so many copies of that protein can be made at the same time by the different ribosomes that are attached to the mRNA. A ribosome starts to translate the mRNA at one end and moves along it translating as it goes. After completing the message, the ribosome is released from the mRNA molecule. This process is shown in the diagram in Figure 4.7

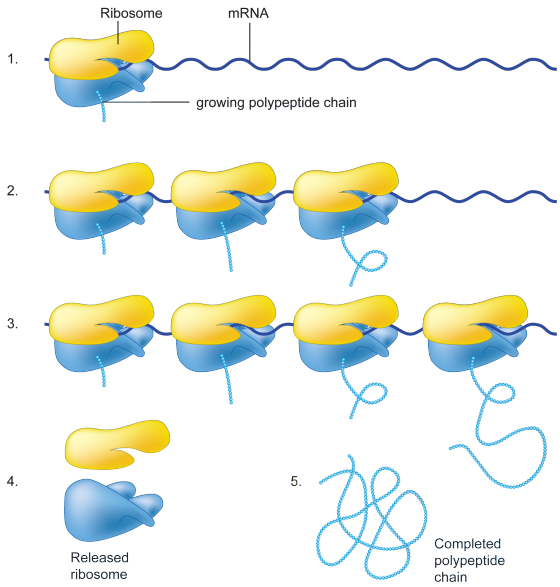


Figure 4.7 The ribosome reads the mRNA in one direction. More than one ribosome can translate the same message into protein at the same time. Each polypeptide chain grows as each amino acid is added, one by one, until the protein is complete.

Apply Your KNOWLEDGE

Consider your answer to the Journal Writing on page 40 with respect to how you would investigate whether different languages are related. How could you investigate whether different animals are related based on their genetic codes and proteins? How could you tell which animals were more and which were less closely related?

Let's take a closer look at how amino acids are added to the growing polypeptide chain. The amino acids are added one by one to form the protein at the ribosomes. How do we know that ribosomes are the place where protein synthesis occurs? Scientists can take ribosomes out of a cell to see what they do. They can get ribosomes to make proteins outside of a cell, so they can study protein synthesis *in vitro*, which means "in glass" in a laboratory. To do this, scientists place ribosomes in a test tube with all of the other factors needed for protein synthesis. Then they add amino acids that are labeled or tagged with radioactivity. The scientists let the ribosomes work with these amino acids for certain lengths of time.

What are the results of this experiment? Where are amino acids added to the growing polypeptide chain? Are the new amino acids added

a. at the tip of the tail?

b. at the end nearest the ribosome?

c. somewhere in the middle of the polypeptide?

First, let's look at what the ribosome and growing protein look like before scientists add the labeled amino acids:

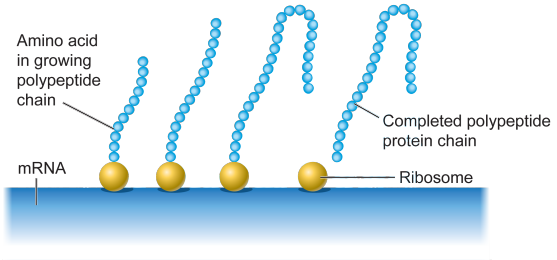


Figure 4.8 Diagram of ribosomes with different length chains of amino acids.

Apply Your KNOWLEDGE

What does "poly" mean in the word *polypeptide?* What are some other words that use "poly" in this way?

Now, let's see how the growing polypeptide chains look after they are exposed to the labeled amino acids for two seconds. The labeled amino acids are indicated as colored circles, while the other amino acids are open circles.

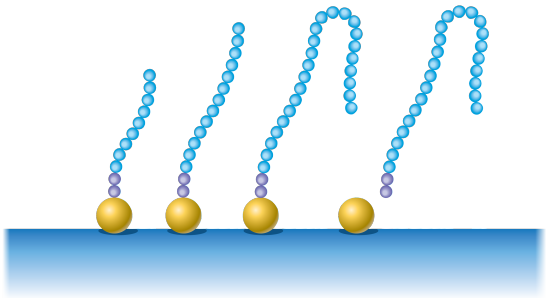


Figure 4.9 Polypeptide chains at the ribosomes after exposure to labeled amino acids for two seconds. Only the most recently added amino acids are labeled.

Now, let's see how the growing polypeptide chains look after they were exposed to the labeled amino acids for one minute.

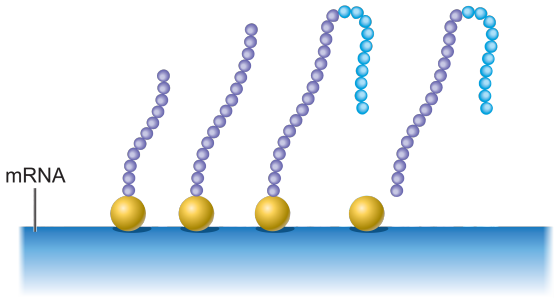


Figure 4.10 Polypeptide chains at the ribosomes after exposure to labeled amino acids for one minute. During one full minute, many amino acids are added.

You can see from Figure 4.10 that the polypeptide chain grows a lot during one minute. Many more amino acids have been added than in the two-second exposure in Figure 4.9. The longer the time of exposure

of the ribosomes to the labeled amino acids, the more amino acids are incorporated into the growing polypeptide chain.

From this experiment you can see that the newly incorporated amino acids are added to the end of the chain that is next to the ribosome. So new amino acids are added to the polypeptide chain at the ribosome.

How do the amino acids necessary for creating the proteins get to the ribosomes? Another type of RNA, called **transfer RNA (tRNA)** brings the amino acids to the ribosomes.

In Figure 4.11 you can see that the transfer RNA has two main functional regions: the anticodon site and the amino acid binding site.

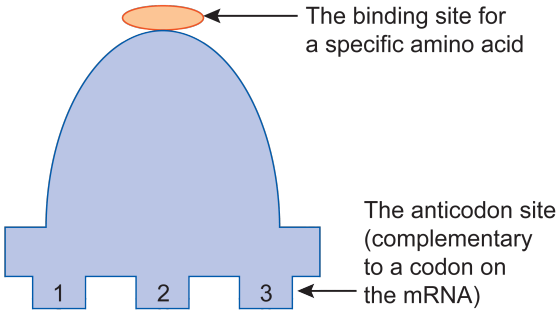


Figure 4.11 A tRNA molecule showing the amino acid and anticodon binding sites.

The amino acid binding site on the tRNA "picks up" a specific amino acid. The anticodon site on tRNA is complementary to a codon on the mRNA. Because of this complementarity between the tRNA and the mRNA, the tRNA molecules line up in a particular sequence along the mRNA. As a result, the amino acids are brought together in the sequence that is coded by the mRNA. Enzymes can then attach the amino acids to each other to form the polypeptide or protein specified by the mRNA.

Apply Your KNOWLEDGE

1. **Write a code using the letters A, U, G, and C for the nucleotides in mRNA.**
2. **Now design the triplets for the transfer RNAs that are complementary to this message.**
3. **What would happen if, in the first triplet, the A was missing and the message began with a U?**
4. **What else could you do that would change (mutate) the original message for making a functional protein into a meaningless message?**

Review Questions

1. Describe how DNA makes a copy of itself.
2. Explain the role of DNA, mRNA, and amino acids in making a protein.
3. What is the genetic code? How does it work?
4. How are amino acids brought into the sequence that is specified by the mRNA code?

Chapter 6

The Health of Cells - Student Edition (Human Biology)

6.1 The Health of Cells

In what ways does your general health depend on the health of your cells?

Cells play many important roles in keeping your body in homeostasis, or internal balance. Cell function is crucial in keeping the levels of ions, proteins, and other factors at normal levels throughout the body. Cells depend on feedback, or information from their environment, in order to keep all the organs and, therefore, the body in working order.

The health of the cells of your body can be affected by many factors. Some factors that affect the function of cells come from within the body. For example, if a blood vessel that serves a portion of the brain becomes clogged or breaks, that region of the brain will not get oxygen or nutrients. Waste products will build up. The cells in that brain region will get sick and may die. This blockage of or break in a blood vessel is called a **stroke.** A stroke results in a loss of the functions of the part of the brain affected.

Other factors that affect the functions of cells come from the environment. For example, air pollution can affect the health of cells in your breathing system. Certain toxic chemicals can cause damage to the DNA in some cells in the body. The normal functions of these cells will be altered. In some cases, their growth may become uncontrolled producing the disease we call cancer. Some external agents that can affect cells and cause serious damage include tobacco smoke (lung cells), solar radiation (skin cells), certain pesticides (liver cells), certain drugs (brain and muscle cells), and organisms such as bacteria and viruses (infection

of any cell in the body).

It seems straightforward to state that diseases like cancer and heart disease are the result of unhealthy or damaged cells, but what about some other diseases or disabilities, such as hearing loss? How are cells involved in those disorders?

If a person listens to extremely loud music regularly, the very delicate sensory cells of the inner ear may be permanently damaged. Once these sensory cells are damaged and lose their function, they cannot repair themselves. The hearing loss may be total if enough sensory cells are damaged. Rock musicians who perform concerts for a number of years can suffer a tremendous loss of hearing. Soldiers who have been exposed to horribly loud explosions of gunfire can suffer "artillery ear" deafness.

In this section you will examine several of the effects on the body when cells do not function normally. We will consider some genetic diseases and cancer.

Mutations

A permanent change in the DNA of a cell is called a **mutation.** Mutations that occur in somatic cells can affect the life of an individual. But mutations that occur in the somatic cells of an individual are not inherited by his or her offspring. If changes in DNA happen in gametes (sperm or egg) or **stem cells** that produce gametes, the mutations may be transmitted to the next generation. Not all mutations are bad, however. Mutations that occurred long ago are the basis for the variety among people and differences between species. Without mutations, life on Earth would not have progressed past the original single-cell stage. There would be none of the current animals and people that we find so fascinating. So changes in DNA are an essential part of the history of life on our planet. In the short run, however, most new mutations are harmful.

Mutations can be caused by factors in the environment, such as solar radiation, and some chemicals. Again, if those factors cause a mutation in a somatic cell, it may affect that individual only. If those factors cause a mutation in the gamete cells, the offspring of that individual could be affected. We do not know the reason that most mutations happen. Most mutations are spontaneous and are not caused by factors in the environment. You learned earlier about DNA replication. The replication of DNA is incredibly accurate. Think about how the cell usually copies the estimated 80,000 to 100,000 genes with great accuracy during every division. It is not surprising that mutations do happen, but it is amazing that they do not happen more often.

Genetic Diseases

Some cells cannot function properly because of a problem in the DNA that the individual inherited from his or her biological parents. The individual may have inherited DNA altered in a particular gene that is crucial for normal cell function. Such an alteration in the genetic code is called a mutation. If there has been a mutation in an important region of the DNA, then the cells of the body that use or express that region of DNA and their daughter cells will not be able to carry out their normal tasks. In some cases an entire organ may not function properly. The function of an organ requires that the great majority of cells that make up the organ function normally. For example, if certain cells of the nervous system don't function, then you might not be able to think well, see clearly, or move properly. If the cells of the lungs don't function, you can't breathe. If the cells of the heart muscle don't work, your heart cannot pump blood.

Genetic diseases are also called hereditary diseases. They are conditions inherited from either one or both parents that are caused by mutations in the DNA. Some genetic diseases are so severe that the embryo or offspring may not be able to survive.

Explain how a mutation in a DNA molecule of only one base could cause a genetic disease in which an essential protein is altered so that it does not function normally. Make sure you explain how each step of protein synthesis is affected.

An Example of a Genetic Disorder

Cystic fibrosis is a genetic disease in which the affected person receives a mutated gene from both the mother and the father. Children with cystic fibrosis have problems with recurring lung infections because certain cells in their lungs do not function properly. They have increasingly difficult health problems with these persistent infections including pneumonia.

Cystic fibrosis patients have a mutation in a gene that makes a protein. In this case it's a membrane protein. This membrane protein allows ions (like chloride) to move across a cell membrane. Because the protein in these cells is altered, the lungs cannot function normally. Figure 5.1 shows how this gene alteration affects the lungs of cystic fibrosis patients.

Without good medical care, children with cystic fibrosis may die at a young age. However, with good medical care and a good program of physical therapy, cystic fibrosis patients can live relatively normal lives. There are very encouraging treatments under development for people with cystic fibrosis, now that scientists have greater knowledge of how cells work. These treatments potentially will save many lives and make life easier for cystic fibrosis patients.

Cancer

What is cancer? What does cancer have to do with cells? **Cancer** is a change in the way cells are able to control their own reproduction. When cancer occurs, the cells lose their normal controls on cell division. Cancer cells continue to divide and produce abnormal tissues called **tumors.**

How Cancer Affects Cells

A cancer cell is different from a normal cell in the way it moves, in its shape, and in the way it responds to chemicals and to nutrients.

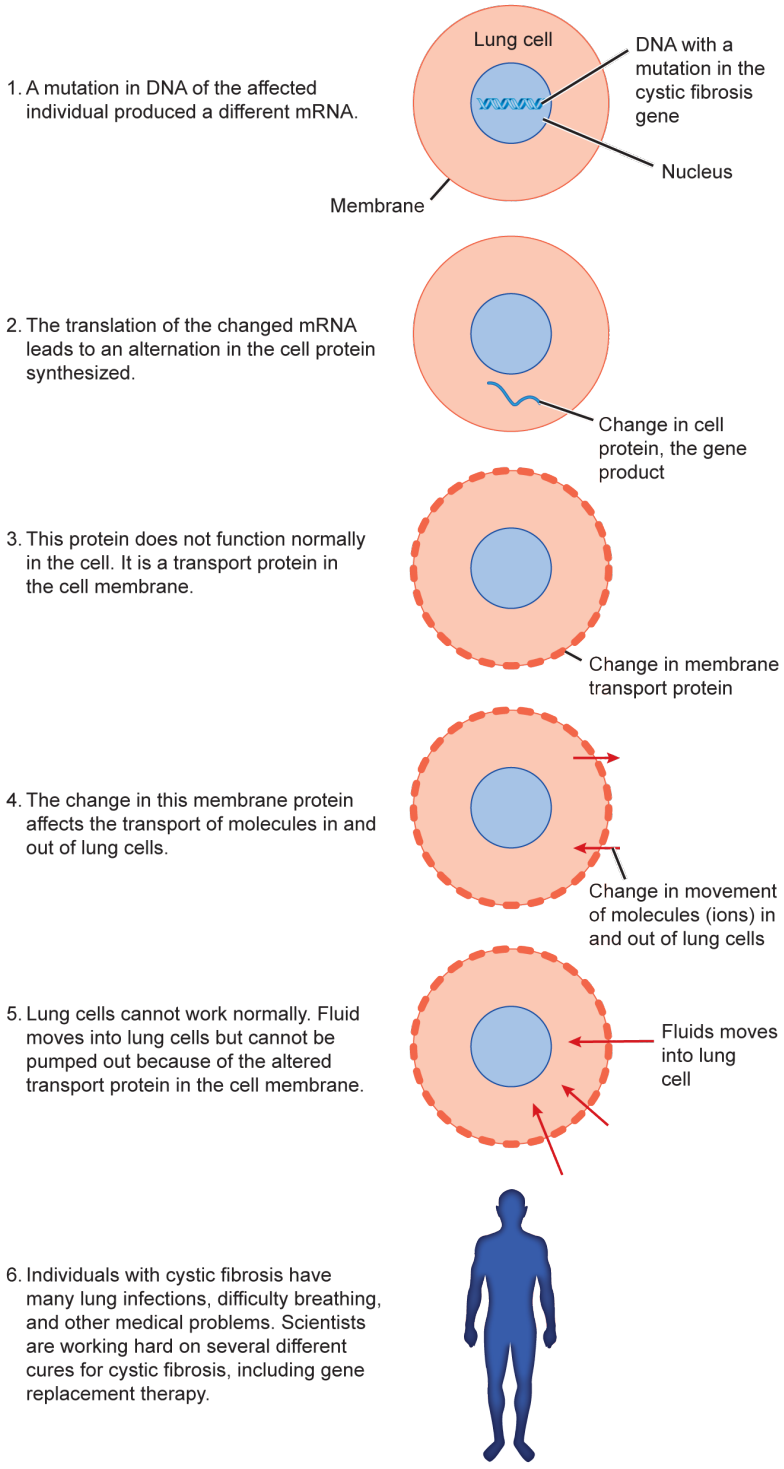


Figure 5.1 Gene alteration affects the lung cells of cystic fibrosis patients.

To learn about cancer, you need to learn more about how normal cells respect each other's space, how they form associations or groups of cells, and how cells recognize each other.

Normal cells don't just sit still. They are active.

- Cells can recognize their neighbors.

- Cells can tell the difference between cells that are like themselves and other cells. For instance, a lung cell can tell the difference between other lung cells and liver cells.
- Cells can stick close to their neighbors or they can keep their distance.
- Cells can send messages. Cells can send each other signals. Some of these signals are specific and can only be read by certain cells.
- Cells can receive and decode messages. They can make special protein products. These products can change the way a person grows and develops.
- Cells can reproduce. They can make more cells.

Cancer cells are abnormal in that they do not recognize and respect the boundaries of cells of different tissues. Cancer cells move and grow where they do not belong. For example, tumor cells that start in the lungs can travel to other tissues and other organs. Tumor cells make associations with these other cells that normal cells would not make. Tumor cells can take over other regions of the body, partly because they do not have the same "respect" for boundaries, for territories, or for "their place" that normal cells have.

Predicting Cancer Risks

How can scientists determine the risk of someone getting cancer? Let's look at the relative risk that a person of a certain age will get colon cancer. In this example, cells of the colon become cancerous. If not detected early, this is a very serious type of cancer that is often fatal. It is extremely rare in young people, yet the risks of getting colon cancer increase dramatically with age. Why is this so?

Let's make some educated guesses about the risks of colon cancer for a child and an older person. First, consider the simplest guess. If the transformation of a normal cell to a cancer cell depends on just one event, then a 70-year-old should have a seven-times greater risk of developing colon cancer than a 10-year-old child does. A single cause (one event) would show a relationship like the one in Figure 5.2.

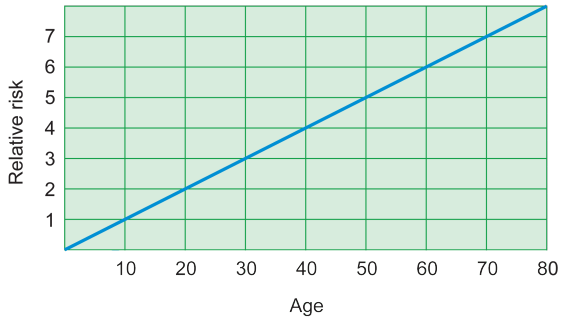


Figure 5.2 Relationship of a single cause.

Now suppose that there is more than one step involved in causing a normal cell in the colon to become cancerous. Suppose there are two events (for example, X-ray exposure and exposure to a chemical). Then you would calculate the risk of cancer over the time period by multiplying the chance of exposure to one event by the chance of exposure to the second event. That would mean that a 70-year-old person might have a 7×7 or 49-times greater risk of developing colon cancer than a 10-year-old child would. This could be graphed as:

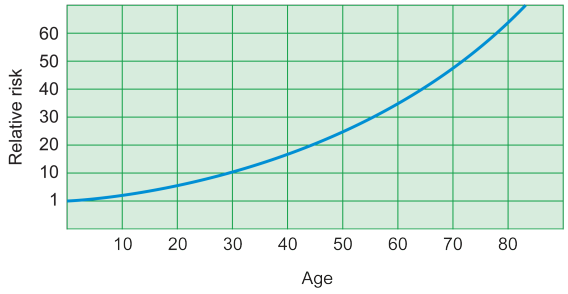


Figure 5.3 Risk for colon cancer of a 70-year-old person compared to that of a 10-year-old person as a result of two events.

Suppose five events are involved in causing a normal colon cell to become cancerous. That would mean that a 70-year-old might have a $7 \times 7 \times 7 \times 7 \times 7$ greater risk of developing colon cancer than a 10-year-old would. The graph of this is shown in Figure 5.4.

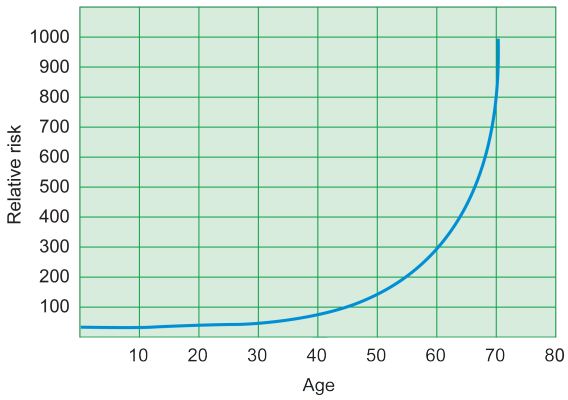


Figure 5.4 Risk for colon cancer of a 70-year-old person compared to that of a 10-year-old person as a result of five events.

How does this series of guesses fit what really happens in a population of people? Let's look at the graphs of the actual number of cases of colon cancer to find out:

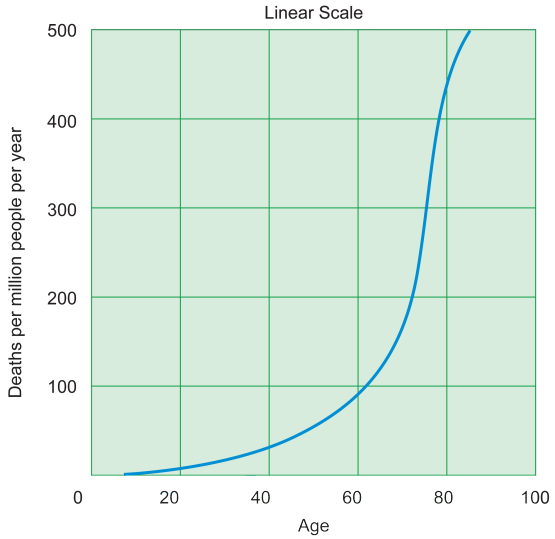


Figure 5.5 The actual annual U.S. death rate from colon cancer in relation to age.

Note that the risk of colon cancer increases as predicted by our third guess-there are five cancer-causing events that occur over a person's life span. The question then becomes, how do you decrease the chance that you, your friend, or a family member will get colon cancer?

Decreasing the Risk of Cancer

If you look at a huge population of people, the chance of death from colon cancer at the various ages fits the estimate that there are five events that take place in the colon cells to cause colon cancer. These events do not need to happen in a particular order. This knowledge is important in planning to protect yourself from colon cancer and from cancer in other tissues and organs of your body. Suppose, for example, that a person smokes as a teenager. Because tobacco contains dozens of chemicals that cause cancer, that exposure could be sufficient to cause cancer over time. By the time that teenage smoker is in her forties she could develop lung cancer. We live in a world where we cannot avoid all dangerous chemicals, but it is clearly smart to avoid the ones that we can. We also can actively participate in working to clean up our environment, so we are exposed to fewer cancer-causing agents.

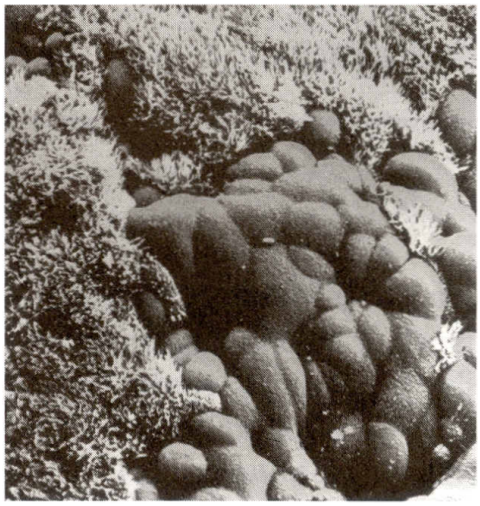


Figure 5.6 The normal lung cells (top) that line the human bronchus have cilia used for defense against debris and microorganisms. The cancerous lung cells (bottom right) are not ciliated and unable to provide defense.

There is now more evidence than ever before suggesting that what you eat can play a big role in your chances of developing certain types of cancer. Eating foods rich in fat causes an increased risk of colon cancer, breast cancer, and cancer of the prostate gland. The typical diet of an American is high in fat. Changing our diets and eating more grains, fruits, and vegetables may help reduce the risk of cancer. Intake of alcohol increases the chance of cancer of the mouth, esophagus, stomach, and possibly even breast cancer, so avoiding or limiting alcohol consumption may also decrease your chance of getting cancer.

Apply Your KNOWLEDGE

What do think happens to the cell cycle in a tumor cell (cancer cell)? You know that tumors can grow very fast. Is that because of changes in the cell cycle of an individual cancer cell or changes in the whole group of cancer cells? Do you think that a cancer cell goes through its cell cycle faster, slower, or at the same rate as a normal cell?

Activity 5-1: Cells Gone Awry

Introduction

What happens when the normal structure of a cell changes? How do you think changes in cells affect the function of the tissue they make up? Do you think the appearance of a cell could be used to explain why it does not function normally? Some cell biologists study differences in cell appearance to learn more about why cells do not work normally.

In this activity you play the role of a pathologist, a scientist who investigates normal and diseased cells. You examine and compare different kinds of tissues to identify changes in their cells that could explain why they may not function correctly.

Materials

- Compound light microscope
- Prepared laboratory slides from blood, lung, or liver tissue
- Activity Report

Procedure

Step 1 Obtain microscope slides of both normal and diseased tissue from the same organ.

Step 2 Examine the normal tissue. On your Activity Report, draw and label each example.

Step 3 Observe the diseased tissue from the same organ. On your activity report, draw and label each example.

Step 4 Select one tissue sample, and compare the similarities between the normal and diseased tissue. On your Activity Report, answer question 3.

Step 5 Clean up. Carefully put away microscope and slides.

Step 6 Complete Activity Report.

Conclusion

Cells, as the building blocks of life, carry out a range of remarkable functions. The diversity of human cell types is astounding: from contracting heart cells, to signaling nerve cells, to swimming sperm cells, to oxygen-carrying red blood cells, to fibroblastic support cells, to light-transmitting lens cells, to natural killer cells of the immune system.

Even more remarkable than cell diversity is the wide spectrum of activities that cells carry out. Networks of communicating compartments within cells build the dynamic cell membranes crucial to cell communication and other functions. Each of the organelles of the cell has a vital function in the life and health of the cell.

Yet, of all the organelles, clearly the control center is the nucleus. Each somatic cell nucleus in a human contains two sets of the 22 autosomes and a pair of sex chromosomes. The gametes (sperm and eggs) contain 1 set of each of the 22 autosomes and only a single sex chromosome. The differences between the cell types of the human body is caused not by differences in DNA content, but by differences in the use or expression of the genes encoded in the DNA. The defining characteristics that distinguish one cell type from another include the content of specific types of protein produced by the different types of cells. In the DNA of the chromosomes, the cell contains the instructions, or blueprint, for that cell's products; the most noteworthy of which are the proteins.

The capacities of a cell for accurate replication of its DNA, for transcription of the DNA into mRNA, and for subsequent translation of the messenger RNA into protein are basic functions of the cell. Without these abilities, life, as it exists on our planet, would be unknown. The ability of cells to carry out behaviors (such as cell recognition and locomotion), to develop into the myriad of diverse cell types, and to make

daughter cells that are exact copies are just a few of the many amazing abilities that cells have. Many of the most fascinating mysteries about cell function await the probing questions of your generation. The wide ranging frontier of the lives of cells is not yet fully mapped.

Review Questions

1. What are mutations? Can they be harmful? Explain.
2. How can mutations be beneficial? Explain.
3. What can you do to reduce your risk of developing cancer? Explain.

Chapter 7

Lives of Cells Glossary - Student Edition (Human Biology)

7.1 Glossary

active transport the use of energy to move materials from a region where they are in a lower concentration to a region where they are in a higher concentration.

adenosine triphosphate (ATP) a compound that stores energy.

amino acids molecules that are the building blocks of proteins.

cancer a change in the way cells are able to control their own reproduction.

cells the basic units (or building blocks) of life. They form the tissues, organs, and systems of the human body.

cell membrane (or plasma membrane) a membrane that surrounds the contents of the cell and separates it from other cells and the environment.

cell theory a theory that states that cells are the units of life and all cells come from preexisting cells.

cellular respiration a process in which glucose is broken down through a series of reactions to produce ATP, as well as carbon dioxide and water.

chromosomes large molecules in the nucleus made up of DNA and protein.

codon a triplet of mRNA nucleotides that directs the placement of an amino acid into a polypeptide chain.

connective tissue a group of cells that support and hold things together.

cystic fibrosis a genetic disease in which the affected person receives a mutated gene from both the mother and the father and has problems with recurring lung infections because certain cells in their lungs do not function properly.

cytoplasm fluid within the cell membrane of a cell that contains water and other chemicals.

diffusion the random movement of molecules from a region of higher concentration to a region of lower concentration.

diploid a cell that has two full sets of chromosomes. In humans, this is 46 chromosomes.

DNA polymerases special enzymes that carry out the neat and orderly replication process of DNA.

double helix two strands that twist around each other like coils. In biology, it refers to the double chain of nucleotides that form a molecule of DNA.

endoplasmic reticulum (ER) an elaborate membrane system throughout the cytoplasm.

enzymes proteins that help chemical reactions take place. Enzymes help cells build products like proteins, make copies of DNA molecules, and carry out all their functions.

epithelial tissue sheets of cells that form your skin, the lining of your breathing and digestive systems, and the covering of the organs of your body.

gamete cells sperm in males or eggs in females.

genes specific regions of the DNA that code for the production of specific proteins. Genes are responsible for specific products and functions characteristic of the particular cell type.

Golgi apparatus the flattened sacs that help sort the proteins synthesized by the rough ER and ribosomes.

haploid having one complete set of chromosomes. In humans a haploid gamete cell has one set of the 23 chromosomes.

helicase an enzyme that helps the DNA molecule start to unwind at one end.

meiosis a special kind of cell division that produces eggs and sperm. It involves two cell divisions, but only one duplication of the genetic materials, so that each daughter cell receives only one chromosome of each chromosome pair, or one complete set of the chromosomes for that organism.

messenger ribonucleic acid (mRNA) a type of nucleic acid that takes the code for a protein from DNA to the ribosome where the protein is produced.

mitochondria cell organelles that are the factory and storage center for ATP, which is used as energy by the cell in making cellular products and carrying out the functions of the cell.

mitosis cell division in which the parent cell reproduces into two identical daughter cells as a result of division of the duplicated chromosomes and division of the cytoplasm.

muscle tissue groups of cells that can contract.

mutation a permanent change in the DNA of a cell.

nervous tissue a group of cells that can process information and send messages or signals.

nucleotides repeating molecular units that make up DNA.

nucleus an important cell organelle that is the control center of the cell, containing the chromosomes with their genetic material, DNA.

organ a group of tissues that work together.

organelles the parts of the cell that are organized for specific functions, such as the nucleus.

osmosis the movement of water across a semipermeable membrane in response to a solute concentration difference.

passive transport the movement of a substance across a membrane due to a concentration difference and not requiring the expenditure of energy.

replication the process through which DNA is copied.

ribosomes the sites for protein synthesis.

RNA polymerase an enzyme that makes a complementary mRNA from the DNA template.

somatic cells almost all the cells in your body-the cells that make up the structure of your body and all your organs, such as the brain, heart, muscles, intestine, and liver. All cells except gamete cells.

stem cell a cell that divides to renew itself and, also, can give rise to many cell types.

stroke the blockage of, or break in, a blood vessel that serves a portion of the brain, causing the cells in that brain region to get sick and/or die.

system organs that work together.

tissue a group of similar cells working together to carry out a specific function.

transcription the process of making a messenger RNA molecule from a segment of DNA.

transfer RNA (tRNA) a type of RNA that brings the amino acids to the ribosomes to make proteins.

translation protein synthesis. The coded message in mRNA is translated to produce a protein.

tumors abnormal tissues produced when cancer cells continue to divide.